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Request for grant of a patent

19 SEP 1997

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1. Your reference

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2. Patent Application Number

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3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

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Patents ADP number *(if known)*

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Country:
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4. Title of the invention

SIGNALLING SYSTEM

5. Name of agent

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6. Priority details

Country	Priority application number	Date of filing
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Patents Form 1/77

7. If this application is divided or otherwise derived from an earlier UK application give details

Number of earlier of application | Date of filing

8. Is a statement of inventorship and or right to grant of a patent required in support of this request?

NO

9. Enter the number of sheets for any of the following items you are filing with this form.

Continuation sheets of this form	0
Description	41
Claim(s)	27
Abstract	1
Drawing(s)	10 ~~X~~ 10

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	1
Request for Substantive Examination *(Patents Form 10/77)*	

11. I/We request the grant of a patent on the basis of this application

Signature Beresford & Co Date 19 September 1997

BERESFORD & Co

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DUPLICATE

SIGNALLING SYSTEM

The present invention relates to a signalling system. The invention is applicable for use in a system for monitoring and/or controlling the cells of an industrial battery.

Industrial batteries comprise a number of rechargeable battery cells which can be electrically connected in various series and series-parallel combinations to provide a rechargeable battery having a desired output voltage. To recharge the battery, a current is passed through the cells in the opposite direction of current flow when the cells are working. There are many different types of battery cells available, but those most commonly used in industrial applications are lead acid battery cells, each of which provides 2 volts, and nickel-cadmium (Nicad) battery cells, each of which provides 1.2 volts.

The batteries are usually used as a back-up power supply for important systems in large industrial plants, such as off-shore oil rigs, power stations and the like. Since the batteries are provided as back-up in the event of a fault with the main generators, they must be constantly monitored and maintained so that they can provide power to the important systems for a preset minimum amount of time.

Many battery monitoring systems have been proposed which monitor the battery as a whole and provide an indication of the battery voltage. However, only a few systems have been proposed which can also monitor the individual cells which make up the battery. These systems use a number of monitoring devices, some of which are powered by the battery cell or cells which they monitor and send status information indicative of the cell voltage back to a central battery monitory system which monitors the battery as a whole.

However, since the cells are connected in series and since each cell monitoring device is powered by the cell which it is monitoring, the ground or reference voltage of each cell monitoring device is different. For example, in an industrial battery which has sixty lead acid cells connected in series, the negative terminal, i.e. the ground, of the fifth cell will be at a potential of approximately 8 volts and the positive terminal will be at a potential of approximately 10 volts, whereas the negative terminal of the seventh cell will be at a potential of approximately 12 volts and the positive terminal will be at a potential of approximately 14 volts. This has lead to the common misconception in the art that the cell monitoring devices have to be electrically isolated from each other and from the

central battery monitoring system.

In one known cell monitoring system, each cell is independently linked to its own electrically isolated input at the central monitoring system. The problem with this system is that a large number of connectors are needed to link the individual cell monitoring devices to the central monitoring system. Consequently, in practice, it is seldom used for permanent real-time monitoring of the battery cells.

In another known cell monitoring system, each cell monitoring device is serially linked to its neighbours in a daisy-chain configuration, either by using optical links between the monitoring devices or by using transformers which have no DC path. The problem with this system is that to operate, each of the cell monitoring devices requires either an electrical to optical and an optical to electrical converter or a modulator and a demodulator, which makes them relatively expensive and inefficient since this additional circuitry requires more power from the cell.

There is therefore a need to provide a simple cell monitoring device which can monitor and report on the status of the cells of the battery, but which consumes minimal power from the cell which it is monitoring.

As mentioned above, existing battery monitoring systems monitor the battery and provide an indication of the battery voltage. However, battery voltage is not an indication of the capacity of the battery, i.e. the ability of the battery to provide energy. There is therefore also a need to provide a battery monitoring system which can give the user a fairly accurate estimate of how much load he can place on a battery and over what period of time.

The inventor has realised that it is possible to overcome the problem of having the cell monitoring devices operating at different voltages using simple electronic components and that therefore, there is no need for electrical isolation between the individual cell monitoring devices and the central monitoring system.

According to a first aspect, the present invention provides a signalling system for use with a plurality of series connected battery cells, comprising: a plurality of cell signalling devices, each to be powered by a respective one or more of the plurality of battery cells; and a communication link connecting the plurality of cell signalling devices in series; wherein each cell signalling device comprises a level shift circuit which is operable to receive signals transmitted from an adjacent cell signalling device to shift the level of the

received signal and to output the level shifted signal for transmission to the communication link. By providing a level shift circuit in each cell signalling device, the cell signalling devices can be linked together in a communication link without the need for electrical isolation between the signalling devices.

The signalling system can be used as part of a battery monitoring and/or control system which is used to monitor and/or control the series connected battery cells. By providing the level shift circuit in each cell signalling device, the signalling system obviates the need for electrical isolation between individual cell signalling devices. Consequently, the communication link can be a simple one-wire communication bus.

Preferably each of the cell signalling devices is able to receive communications from and transmit communications to the communication link so that they can communicate with, for example, the battery monitoring and/or control system. In which case, each cell signalling device can comprise two DC level shift circuits, one for increasing the level of the received signals for transmission to a cell signalling device having a higher ground potential than that of the receiving cell signalling device, and one for reducing the level of the received signals for transmission to a

cell signalling device which has a lower ground potential than that of the receiving cell signalling device.

Each level shift circuit can comprise a simple electronic device, such as a comparator, which consumes a relatively small amount of power from the battery cell which powers the cell signalling device.

The first aspect of the present invention also provides a cell signalling device for use in the above defined signalling system, comprising: a power input terminal connectable to the cell or cells which is or are to power the cell signalling device; and at least one DC level shift circuit for receiving signals from an adjacent cell signalling device, for shifting the level of the received signal, and for outputting the level shifted signal for transmission to the communication link.

The first aspect of the present invention also provides a signalling kit comprising a plurality of the cell signalling devices defined above. The kit may also comprise the communication link for connecting the cell signalling devices in series.

The first aspect of the present invention also provides a signalling method using a plurality of series connected battery cells, comprising the steps of: providing a

plurality of cell signalling devices and powering them with a respective one or more of the plurality of battery cells; providing a communication link which connects the plurality of cell signalling devices in series; receiving signals transmitted from an adjacent cell signalling device; shifting the level of the received signals; and outputting the level shifted signals to the communication link.

The inventor has realised that a more accurate estimation of the battery capacity can be given by considering the total charge stored in the battery and to monitor the amount of charge which is drawn from the battery during a discharging operation and the charge which is supplied to the battery during a charging operation.

According to a second aspect, the present invention provides an apparatus for estimating the total working capacity of a battery, comprising a first input terminal for receiving a signal indicative of the current drawn from or supplied to the battery; a second input terminal for receiving a signal indicative of the battery voltage; means for causing the battery to discharge from a fully charged condition in which no more charge can be stored in the battery to a fully discharged condition in which the battery voltage has been reduced to a predefined minimum operating voltage; means for determining the

period of time during which said battery is discharged; and means for estimating the total working capacity of the battery in dependence upon said period of time and upon the current drawn from the battery during said period of time.

Preferably, the total working capacity of the battery is estimated in dependence upon a weighting factor indicative of the discharging efficiency of the battery for at least one sensed operating condition as this provides a more accurate estimation. The discharging characteristics of the battery may be pre-stored in the apparatus for different operating conditions, and an appropriate weighting factor may be determined in dependence upon the sensed operating condition.

The second aspect of the present invention also provides an apparatus for monitoring a battery, comprising a first input terminal for receiving an input signal indicative of the level of current drawn from or supplied to the battery; a second input terminal for receiving an input signal indicative of the voltage of the battery; and the above described apparatus for estimating the total working capacity of the battery.

Preferably, the apparatus for monitoring the battery can estimate the remaining capacity of the battery by

estimating the change in capacity since the last estimate in dependence upon the level of current drawn from and/or supplied to the battery since the last estimate and upon the period of time since the last estimate. This provides users with an indication of how much energy is left within the battery. Preferably, the change in capacity is weighed by a weighting factor which is indicative of the charging and/or discharging efficiency of the battery for at least one sensed operating condition of the battery, since this provides a more accurate estimation.

The second aspect of the present invention also provides a method of estimating the total working capacity of a battery, the method comprising the steps of causing the battery to discharge from a fully charged condition in which no more charge can be stored in the battery to a fully discharged condition in which the battery voltage has been reduced to a predefined minimum operating voltage; determining the period of time during which the battery is discharged; and estimating the total working capacity of the battery in dependence upon said period of time and upon the current drawn from the battery during said period of time.

The present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 schematically shows a battery comprising a number of battery cells connected in series, a central battery monitoring system for monitoring the condition of the battery as a whole and individual cell monitoring devices for monitoring the cells of the battery;

Figure 2 is a schematic diagram showing more detail of the central battery monitoring system shown in Figure 1;

Figure 3 is a schematic diagram of one of the cell monitoring devices shown in Figure 1;

Figure 4 is a plot showing the battery-cell voltage distribution;

Figure 5a is a circuit diagram of a first comparator forming part of the cell monitoring device shown in Figure 3;

Figure 5b is a circuit diagram of a second comparator forming part of the cell monitoring device shown in Figure 3;

Figure 5c is a schematic representation showing part of the battery-cell staircase voltage distribution and example data pulses which are applied to the input of the comparators shown in Figures 5a and 5b;

Figure 6 is a schematic diagram of a battery cell monitoring device for use in a battery monitoring system according to a second embodiment of the present invention;

Figure 7 schematically shows a battery comprising a number of battery cells connected in series, a central battery control system for controlling the battery as a whole and individual battery cell controllers for controlling the cells of the battery;

Figure 8 is a schematic diagram of one of the battery cell control devices shown in Figure 7;

Figure 9 is a schematic diagram of a battery cell monitoring and control device for use in a battery monitoring and control system embodying the present invention;

Figure 10 is a schematic representation of an industrial battery in which the cells of the battery are connected in a series-parallel configuration; and

Figure 11 is a schematic diagram of a system for monitoring a plurality of industrial batteries.

A first embodiment of the present invention will now be described with reference to Figures 1 to 5. Figure 1

schematically shows an industrial battery, generally indicated by reference numeral 1, comprising a number of lead acid battery cells C_1, C_2, C_3 ... C_n connected so that the negative terminal C_i^- of cell C_i is connected to the positive terminal C_{i-1}^+ of preceding cell C_{i-1} and the positive terminal C_i^+ of cell C_i is connected to the negative terminal C_{i+1}^- of the succeeding cell C_{i+1}, whereby the negative terminal C_1^- of the first cell C_1 is the negative terminal of the battery and the positive terminal C_n^+ of the last cell C_n is the positive terminal of the battery. Since the battery cells are lead acid, they each provide approximately 2 volts and the voltage of the battery as a whole will be approximately 2n volts. For industrial applications a voltage of 120 volts is often required. Therefore, 60 series connected lead acid or 100 series connected Nicad battery cells would be required. Sometimes, each cell in the series connection is connected in parallel with one or more similar cells, so as to provide redundancy, so that the battery will not fail if a single cell fails.

Figure 1 also shows a central battery monitoring system 3 which is powered by the battery 1 via connectors 4 and 6, which connect the central battery monitoring system 3 to the negative terminal C_1^- and the positive terminal C_n^+ of the battery 1, respectively. The battery monitoring system 3 monitors the status of the industrial battery 1 as a whole, based on charging and discharging

characteristics of the battery (determined by monitoring the battery voltage from connectors 4 and 6 and the current being drawn from or supplied to the battery 1, which is sensed by current sensor 8, whilst the battery is being charged and subsequently discharged), the ambient temperature (input from temperature sensor 5) and on information relating to the efficiency characteristics of the battery cells (provided by the battery cell manufacturer). The monitoring results can be stored in the central battery monitoring system 3 or they can be transmitted to a remote user (not shown) via the telephone line 7.

Each of the battery cells C_i, shown in Figure 1, also has a battery cell monitoring device CM_i mounted on top of the cell between its positive and negative terminals C_i^+ and C_i^- respectively, which monitors the status of the cell C_i. Each cell monitoring device CM_i is powered by the cell C_i which it monitors and communicates with the central battery monitoring system 3 via a simple one-wire communication link 9. The communication link 9 links the cell monitoring devices CM_i in series in a daisy chain configuration to the central battery monitoring system 3, so that communications from the central battery monitoring system 3 to the cell monitoring devices CM_i pass from left to right along the communication link 9

and communications from the cell monitoring devices CM_i to the central battery monitoring system 3 pass from right to left along the communication link 9. Each cell monitoring device CM_i has its own cell identification or address, which, in this embodiment, is set in advance using DIP-switches mounted in the device. This allows communications from the central battery monitoring system 3 to be directed to a specific cell monitoring device and allows the central battery monitoring system 3 to be able to identify the source of received communications.

The battery monitoring system shown in Figure 1 operates in two modes. In the first mode, the central battery monitoring system 3 monitors the condition of the industrial battery 1 as a whole and polls each of the cell monitoring devices CM_i in turn. During this mode, each of the cell monitoring devices CM_i listens to communications from the central battery monitoring system 3 on the communication link 9 and responds when it identifies a communication directed to it. When polled, each cell monitoring device CM_i performs a number of tests on the corresponding battery cell C_i and returns the results of the tests back to the central battery monitoring system 3 via the communication link 9.

In the second mode of operation, the central battery

monitoring system 3 listens for communications on the communication link 9 from the cell monitoring devices CM_i indicating that there is a faulty condition with one of the battery cells C_i. In this second mode of operation, each cell monitoring device CM_i continuously monitors the corresponding battery cell C_i and, upon detection of a faulty condition, checks that the communication link 9 is free and then sends an appropriate message back to the central battery monitoring system 3 via the communication link 9.

Figure 2 is a schematic diagram of the central battery monitoring system 3 shown in Figure 1. As shown, the central battery monitoring system 3 comprises a CPU 11 for controlling the operation of the central battery monitoring system 3. The CPU 11 is connected, via data bus 12, to a main memory 13 where data from the input sensors is stored and where test programs are executed, to a display 15 which displays the battery's current status and to a mass storage unit 17 for storing the sensor data and the results of the battery tests. The mass storage unit 17 can be fixed within the central battery monitoring system 3, but is preferably a floppy disk or a PCMIA memory card which can be withdrawn and input into an operator's personal computer for analysis. An operator can also retrieve the stored data and results

and control the set up and initialisation of the central battery monitoring system 3 via the RS-232 serial interface 18. As mentioned above, instead of storing the test results in the mass storage unit 17, they can be transmitted via a modem 21 and telephone line 7 to a remote computer system (not shown) for display and/or analysis.

The central battery monitoring system measures the total battery capacity in Amp-hours (Ahr) or Watt-hours (Whr), the actual or remaining battery capacity as a percentage of the total battery capacity and the internal resistance of the battery 1 as a whole. The cental battery monitoring system 3 can also measure the internal resistance of the individual cells from the data received from the individual cell monitoring devices CM_i received via the communication link 9 and the communication circuit 19.

In order to be able to measure the total battery capacity, i.e. the maximum amount of charge which can be stored in the battery, and the actual or remaining battery capacity at a given time point as a percentage of the total battery capacity, the central battery monitoring system 3 monitors how much charge is fed into the battery and how much charge is drawn from the battery. Unfortunately, since the charging and

discharging characteristics of the battery are not one hundred percent efficient. Therefore, the estimated capacity derived by monitoring the charge alone is not very accurate. In fact, various factors affect the amount of charge which is input to or drawn from a battery during charging/discharging, including the ambient temperature, the magnitude of the charging/discharging current, the algorithm used for charging etc. Fortunately, many of these characteristics are known to the battery manufacturer and, in this embodiment the specific characteristics of the battery 1 are programmed into the central battery monitoring system 3. With this information, it is possible to determine more accurately how much charge has been stored in or withdrawn from the battery 1.

For example, if the battery 1 is charged with a charging current of 10 amps over a period of two hours at an ambient temperature of 20°C, and it is known that the efficiency characteristic of the battery is 95% for such a level of charging current and for that ambient temperature, then the total charge supplied to the battery is 19 Ahr. In the general case, for a current ($I(t)$) drawn from or supplied to the battery, the capacity (CP) added to or removed from (depending on whether the current is negative or positive) the battery from time t_0 to time t_1 is given by:

$$CP[t_0, t_1] = (k_1 \times k_2 \times k_3) . \int_{t_0}^{t_1} I(t)\, dt \qquad (1)$$

where k_i are the efficiency characteristics for the battery 1 for the sensed conditions and where I(t) is negative when the current is being drawn from the battery 1.

In order to determine the initial total battery capacity (TCP), the battery 1 is initially fully charged by charging the battery for a long period of time using a small charging current. Then the battery 1 is discharged through a load (not shown) until the battery voltage drops below an end of discharge voltage limit (EODV) which is specified by the battery manufacturer. During this discharging period, the central battery monitoring system 3 monitors the discharge current via current sensor 8, and once the EODV limit is reached, it calculates the capacity (in Amp-hours) which has been removed from the battery using equation 1 above, with t_0 being the time that the discharge is initiated and time t_1 is the time that the EODV limit is reached. This capacity represents the total battery capacity (TCP).

In this embodiment, the central battery monitoring system 3 periodically determines the remaining battery capacity

(RCP) as a percentage of the total battery capacity (TCP) by monitoring the amount of current which is drawn from and/or supplied to the battery 1 since the last time the remaining battery capacity was determined and then by using the following equation:

$$RCP[t_1] = RCP[t_0] + \frac{100.CP[t_0,t_1]}{TCP} \qquad (2)$$

Where $CP[t_0,t_1]$ is calculated using equation 1 above. The initial estimate for the remaining battery capacity is set equal to the total working capacity of the battery after the battery has been fully charged.

To determine the internal resistance of the battery as a whole, the battery is connected to two different loads and the central battery monitoring system 3 monitors the current through the loads from which it determines the internal resistance of the whole battery.

As mentioned above, in addition to determining the total battery capacity, the remaining battery capacity and the battery internal resistance, the central battery monitoring system 3 also monitors data received from the cell monitoring devices CM_i via the communication circuit 19 and the communication link 9. If there is a fault

with one of the battery cells C_i or if there is some other faulty condition, the CPU 11 can trigger a local alarm 23 to alert a technician that there is a fault with the battery 1 or with one or more of the battery cells C_i. In this embodiment, the conditions which define a fault and their thresholds are user definable and set in advance.

Although the central battery monitoring system 3 continuously monitors the battery 1, the sensor data and the other battery data, i.e. the remaining battery capacity etc, are only stored periodically in the mass storage unit 17 in order to save storage space. The period is specified in advance by the user and in this embodiment is set at ten seconds. Furthermore, when the samples are stored, they are time and date stamped so that the battery charging and discharging behaviour can be monitored and used to detect the cause of an eventual battery failure. In this embodiment, the data which is to be stored is also filtered in order to try to identify and highlight important events, and the filtered data is also stored in the mass storage unit 17. What counts as an important event is user definable, but can be, for instance, a temperature increase of 2°C or a change in remaining battery capacity of greater than 1% of the total battery capacity.

As mentioned above, the status data of the battery, i.e. the battery voltage, the discharge/charge current, the battery temperature and the remaining and total battery capacities, are displayed on display 15. For simplicity, since the display 15 does not need to be continuously updated, it is only updated using the samples of the status data which are to be stored in mass storage unit 17. Therefore, in this embodiment, the display 15 is updated every ten seconds.

In this embodiment, the central battery monitoring system 3 is also used to control the battery charger (not shown) which is used to charge the battery 1. In particular, the central battery monitoring system 3 monitors the charging current, the remaining battery capacity, the ambient temperature etc and controls the operation of the charger (not shown) so that the battery charging is in accordance with the specific charging procedures recommended by the battery manufacturer for the battery 1.

Since the total battery capacity also decreases with time (due to ageing), the central battery monitoring system 3 is programmed to perform regular (for example daily or monthly) automated measurements of the total battery capacity and the battery internal resistance using the procedures outlined above. This allows the central

battery monitoring system 3 to be able to build up a picture of the battery life characteristics and to be able to predict the battery end of life and the early detection of faulty conditions.

Figure 3 is a schematic diagram showing, in more detail, one of the cell monitoring devices CM_i. As shown, cell monitoring device CM_i comprises a microcontroller 31 for controlling the operation of the cell monitoring device CM_i and for analysing sensor data received from voltage interconnection sensor 33, cell voltage sensor 35, temperature sensor 37 and electrolyte level/PH sensor 39.

The voltage interconnection sensor 33 measures the voltage drop between the cell being monitored and its neighbouring cells, by measuring the potential difference between each terminal of the cell C_i and the respective terminal connections which connects cell C_i with its neighbouring cells. Ideally, there should be no voltage drop between each terminal and the corresponding terminal connection. However, due to chemical deposits accumulating at the cell terminals with time, or because of cell malfunction, a difference in potential between the cell terminals and the corresponding connectors sometimes exists, indicating that there is a fault, either with the battery cell C_i or with the

interconnection with a neighbouring cell.

The cell voltage sensor 35 is provided for sensing the potential difference between the positive terminal C_i^+ and the negative terminal C_i^- of the cell C_i which it is monitoring. The temperature sensor 37 senses the cell temperature locally at the cell C_i. By monitoring the local temperature at each cell C_i, it is possible to identify quickly faulty cells or cells which are not operating efficiently. The electrolyte level/PH sensor senses the electrolyte level and/or the electrolyte PH of the battery cell C_i which it is monitoring.

The microcontroller 31 analyses the data input from the sensors and monitors for faulty conditions and reports to the central battery monitoring system 3 via the communication link 9. Since the microcontroller 31 processes digital data, and since the signals received from the sensors and the messages received from the battery monitoring system 3 are analogue signals, the microcontroller 31 has a built-in analogue to digital convertor (not shown) so that it can convert the sensor data and the received messages into corresponding digital signals.

Since the cell monitoring devices are connected in series

by the communication link 9, each cell monitoring device CM_i will either receive communications originating from the central battery monitoring system 3, from the left hand side of the communication link 9 for transmission to the next cell monitoring device CM_{i+1}, or they will receive communications from cell monitoring device CM_{i+1} from the right hand side of the communication link 9 for transmission back to the central battery monitoring system 3. In order to compensate for the difference in reference voltages between each of the cell monitoring devices CM_i, each cell monitoring device CM_i has an up-link 41 for transmitting data received from cell monitoring device CM_{i-1} to cell monitoring device CM_{i+1}, and a down-link 43 for transmitting data received from cell monitoring device CM_{i+1} to cell monitoring device CM_{i-1}.

The up-link 41 has a transceiver 45 for increasing the reference voltage of the data signal so that it can be received by the next cell monitoring device CM_{i+1}, while the down-link 43 has a transceiver 47 which reduces the reference voltage of the received data so that it can be received by the cell monitoring device CM_{i-1}. The up-link 41 and the down-link 43 are connected to the one wire communication link 9 via switches 49 and 51 which are controlled by microcontroller 31, as represented by

arrows 52. The way in which the microcontroller 31 controls the position of the switches 49 and 51 for the above described two modes of operation will be apparent to those skilled in the art and will not be described here. The microcontroller 31 is connected to the up-link 41 by connection 53 so that it can listen for communications sent from the central battery monitoring system 3 which are directed to it. Similarly, the microcontroller 31 is connected to the down-link 43 by connection 55 so that the microcontroller 31 can send messages back to the central battery monitoring system 3, either upon being polled or upon detection of a fault.

In order to power the cell monitoring device CM_i, the positive terminal C_i^+ and the negative terminal C_i^- of cell C_i are connected to the input of a DC to DC convertor 57, which generates, relative to the ground or reference voltage V_{REF}^i of cell C_i (which equals the voltage potential of the negative terminal C_i^- of cell C_i) the voltages $V_{REF}^i \pm 5V$, which are used to power the microcontroller 31 and the transceivers 45 and 47.

Figure 4 shows the voltage characteristic of the industrial battery showing each cell's terminal potential versus the cell's position in the series. As shown in

Figure 4, this voltage characteristic has a staircase shape, with each stair having a height equal to the voltage V_{CELL} of the respective battery cell C_i. Each cell monitoring device CM_i uses the fact that there is only a small difference between the reference voltages of adjacent cells and that therefore the transceivers 45 and 47 only have to increase or decrease the reference voltage of the received data by this voltage difference.

In this embodiment, the transceivers 45 and 47 comprise voltage comparators and the messages transmitted to and from the central battery monitoring system 3 are encoded within the transitions of a square wave signal. Figure 5a is a circuit diagram of a voltage comparator 61 forming part of the transceiver 45 provided in the up-link 41 shown in Figure 3. The limits of the comparator 61 are V_{REF}^{i} + 5V and V_{REF}^{i} - 5V, which are generated by the DC to DC converter 57. Figure 5b is a circuit diagram of a voltage comparator 63 forming part of the transceiver 47 provided in the down-link 43 shown in Figure 3. As with comparator 61, the limits of comparator 63 are V_{REF}^{i} + 5V and V_{REF}^{i} - 5V.

Figure 5c shows part of the battery-cell voltage distribution shown in Figure 4 and, superimposed thereon, data pulses for illustrating the way in which data is

passed along the communication link 9. The left-hand side of Figure 5c shows the ground or reference voltage V_{REF}^{i-1} for cell C_{i-1} and shows that data pulses 65 output by cell monitoring device CM_{i-1} vary between V_{REF}^{i-1} + 5V and V_{REF}^{i-1} - 5V. In this embodiment, when the data is originally transmitted from the central battery monitoring system 3, the data pulses 65 will be transmitted from cell C_{i-1} to cell C_i and will be applied to the positive input of the comparator 61 on the up-link 41 of cell monitoring device CM_i via switch 49. As shown in Figure 5a, the received pulses are compared with V_{REF}^{i} - 2V (which is an approximation of the reference voltage V_{REF}^{i-1} of the cell C_{i-1} which generated the received pulses 65, since the cells are lead acid battery cells which provide approximately 2 volts each) and the data pulses 67 output by comparator 61 will correspond with the received data pulses 65 but will vary between V_{REF}^{i} + 5V and V_{REF}^{i} - 5V, as shown in the middle of Figure 5c. Therefore, the DC level of the square wave pulses has been increased by passing it through the comparator 61.

The output data pulses 67 are transmitted to the next cell monitoring device CM_{i+1} via switch 51 and communications link 9. The data pulses 67 output from comparator 61 are also input to the microcontroller 31

via connection 53, so that the microcontroller 31 can identify whether or not the communication from the central battery monitoring system 3 is directed to it. If the communication is directed to it, the microcontroller 31 processes the request, performs the necessary tests and transmits the appropriate data back to the central battery monitoring system 3.

When data pulses 69 are transmitted to cell monitoring device CM_i from cell monitoring device CM_{i+1} for transmitting back to the central battery monitoring system 3, the received data pulses 69, which vary between V_{REF}^{i+1} + 5V and V_{REF}^{i+1} - 5V, are applied to the positive input of comparator 63 on the down-link 43 of cell monitoring device CM_i via switch 51. As shown in Figure 5b, the received pulses 69 are compared with V_{REF}^{i} + 2V (which is an approximation of the reference voltage V_{REF}^{i+1} of the cell C_{i+1} which generated the received pulses 69, since the cells are lead acid battery cells which provide approximately 2 volts each). As shown in Figure 5c, this comparison results in a series of pulses 67 corresponding to the received pulses 65 but which vary between V_{REF}^{i} ± 5V which are transmitted to cell C_{i-1} via switch 49. Therefore, the DC level of the square wave pulses has been reduced by passing it through the comparator 63.

Each of the cell monitoring devices CM_i operate in a similar manner. However, it should be noted that the first cell monitoring device CM_1 has the same ground or reference voltage as the central battery monitoring system 3. Therefore, it is not necessary to use a transceiver 45 in the up-link 41 of the first cell monitoring device CM_1, although one is usually used in order to buffer the received signals and in order to standardise each of the cell monitoring devices CM_i. Similarly, the last cell monitoring device CM_n will not receive data pulses from a subsequent cell monitoring device and therefore, does not need a transceiver 47 in its down-link. However, one is provided so that all the cell monitoring devices CM_i are the same, and is used for buffering the data sent from microcontroller 31 of cell monitoring device CM_n back to the central battery monitoring device 3.

The battery monitoring system described above has the following advantages:

(1) There is no need for voltage isolation between the cell monitoring devices CM_i or between the first cell monitoring device CM_1 and the central battery monitoring system 3. Therefore, each cell monitoring device CM_i will only consume a few milli-amps and only requires very

inexpensive and readily available DC to DC converters for converting the battery cell voltage to the supply voltage needed by the microcontroller 31 and the transceivers 45 and 47.

(2) Since electrical isolation is not required between the cell monitoring devices CM_i, there is no longer a need for relatively expensive voltage isolated links between the cell monitoring devices. In the embodiment described, each cell monitoring device CM_i is linked to its neighbours by a simple wire. The cost of the battery monitoring system is therefore low and system installation is simplified.

(3) Continuous monitoring of all the cells C_i in battery 1 becomes economical and practical, and the user can be informed in real-time if one or more of the battery cells C_i is under performing or is faulty.

(4) The internal resistance of each cell C_i can be determined in real-time and without having to disconnect the cell from the battery, since the central battery monitoring system 3 is capable of measuring battery charging and discharging current (which is the same as the cell current) and can correlate it with individual cell voltages (determined by the cell monitoring devices)

in order to calculate each cell's internal resistance.

(5) Each cell monitoring device CM_i is able to measure the voltage drop on cell to cell interconnections and indicate a faulty interconnection condition, usually due to chemical deposits accumulating at the cell terminals with time or because of cell malfunction.

(6) Since each cell monitoring device CM_i is able to measure the cell voltage and the cell temperature, it is possible to increase the probability of detecting a faulty cell. Therefore, the industrial battery need only be serviced when required.

(7) Since each cell monitoring device CM_i can read the corresponding cell voltage, cell temperature etc at the same time as the other cell monitoring devices, the data produced by each cell monitoring device is less likely to be corrupted by changes in load and/or changes in ambient temperature which occur with time, as compared with prior art systems which take readings from the individual cells one at a time.

A number of alternative embodiments will now be described, which operate in a similar manner to the first embodiment. Accordingly, the description of these

alternative embodiments will be restricted to features which are different to those of the first embodiment.

In the first embodiment, each cell monitoring device CM_i has a microcontroller 31 for receiving messages from the central battery monitoring system 3, for analysing data from various sensors and for sending data back to the central battery monitoring system 3 via the communication link 9. Figure 6 schematically shows an alternative cell monitoring device CM_i of a second embodiment which does not use a microcontroller 31.

In particular, as shown in Figure 6, each cell monitoring device CM_i comprises a signal generator 71 which receives sensor signals from the cell voltage sensor 35 and the temperature sensor 37 and outputs, on line 73, a signal which varies in dependence upon the received sensor signals. The signal generator 71 may comprise a voltage controlled oscillator which outputs an alternating signal whose frequency varies in dependence upon an input voltage from, for example, the cell voltage sensor 35. The signal output from the signal generator 71 is applied to an output terminal 75 for transmission to the central battery monitoring system 3, via the communication link 9. In this embodiment, each cell monitoring device CM_i only transmits signals back to the central battery

monitoring system 3, they can not receive messages from the central battery monitoring system. Therefore, only a down-link is required to receive signals at input terminal 77, transmitted from cell monitoring device CM_{i+1}.

As in the first embodiment, each cell monitoring device CM_i is powered by the cell C_i which it is monitoring. This is illustrated in Figure 6 by the connections C_i^+ and C_i^- which are connected to input terminals 74 and 76 respectively. Since the communication link 9 connects each of the cell monitoring devices CM_i in series in a daisy chain configuration, cell monitoring device CM_i will receive signals, at input terminal 77, from cell monitoring device CM_{i+1}. The received signals are applied to a DC level shift circuit 79 which reduces the DC level of the received signals and supplies them to the output terminal 75 for transmission to the next cell monitoring device CM_{i-1} in the communication link 9.

In the first two embodiments, the system described was a battery monitoring system. Figure 7 schematically shows a third embodiment which is a control system for controlling the cells of an industrial battery. As shown, the control system has a similar architecture to the battery monitoring system shown in Figure 1, except

that the central battery monitoring system 3 is now a central battery control system 80 and the cell monitoring devices CM_i are now battery cell control devices CC_i. As in the monitoring system of Figure 1, the central battery control system 80 communicates with each of the cell controlling devices CC_i via the communication link 9.

Figure 8 schematically shows one of the battery cell control devices CC_i shown in Figure 7. Each cell controlling device CC_i is used to control the topping up of acid and water in the respective battery cell C_i, in response to an appropriate control signal received from the central battery control system 80. As in the first embodiments, each cell control device CC_i is powered by the cell which it is to control, as represented by inputs C_i^+ and C_i^- applied to input power terminals 81 and 85 respectively. In this embodiment, each cell controlling device CC_i is arranged to receive messages from the central battery controlling system (not shown), but not to transmit messages back. Accordingly, signals received at the input terminal 85 from cell controller CC_{i-1} are applied to DC level shift circuit 87, which increases the DC level of the received signals and outputs them to output terminal 89 for transmission to the next cell controlling device CC_{i+1}. The microcontroller 91 monitors the received signals via connection 93 and outputs

appropriate control signals to output terminals 95 and 97 when the received signals are directed to it. The control signals output to terminals 95 and 97 are used to control the position of valves 99 and 101 respectively, so as to control the amount of water and acid to be added to the battery cell C_i from the water tank 103 and the acid tank 105. The microcontroller 91 determines the amount of water and acid to add with reference to the sensor signals received from the electrolyte level/PH sensor 39.

In the first three embodiments, a central battery monitoring system or a central battery control system was provided which monitored or controlled the system as a whole. Figure 9 schematically shows a cell monitoring and control device $CM\&C_i$ which can be used in a combined battery control and monitoring system in which there is no central battery monitoring and control system and in which each cell monitoring and control device $CM\&C_i$ communicates directly with the other cell monitoring and control devices. As in the other embodiments, each cell monitoring and control device $CM\&C_i$ is powered by the cell which it is monitoring and controlling, as represented by inputs C_i^+ and C_i^- applied to input power terminals 115 and 117 respectively.

As shown in Figure 9, each cell monitoring and control device $CM\&C_i$ comprises a microcontroller 111 which receives sensor data from temperature sensor 37 and which outputs control data to output terminal 113 for controlling, for example, a liquid crystal display (not shown) mounted on the respective cell C_i.

In this embodiment, the communication link comprises two wires 9a and 9b and therefore, switches 49 and 51 are not required to connect the up-link and the down-link to the communication link 9. Wire 9a is used for passing communications up the series communication link 9 from cell monitoring and control device $CM\&C_i$ to cell monitoring and control device $CM\&C_{i+1}$ and wire 9b is used for transmitting signals down the series communication link 9 from cell monitoring and control device $CM\&C_i$ to cell monitoring and control device $CM\&C_{i-1}$. Accordingly, the signals received by cell monitoring and control device $CM\&C_i$ at input terminal 119 are applied to DC level shift circuit 121 which increases the DC level of the received signals and outputs them to output terminal 123 for transmission to cell monitoring and control device $CM\&C_{i+1}$. Similarly, signals received at input terminal 125 are applied to DC level shift circuit 127 which decreases the DC level of the received signals and outputs them to output terminal 129 for transmission to

cell monitoring and control device $CM\&C_{i-1}$. As shown, microcontroller 111 can receive data from and transmit data to both the up-link 9a and the down-link 9b via connections 131 and 133 respectively.

Various modifications which can be made to the above described embodiments will now be described.

In the first embodiment, the transceivers 45 and 47 used in the up-link and the down-link within each cell monitoring device CM_i comprises a voltage comparator. Other types of transceivers could be used. For example, voltage to current and current to voltage comparators could be used. In such an embodiment, the voltage to current comparators and the current to voltage comparators would be arranged alternatively along the communication link 9 so that a voltage to current comparator is connected to the input of a current to voltage comparator, and vice-versa. It is also possible to use other devices instead of comparators in order to raise or lower the reference voltage of the data being transmitted between cells, such as solid state analogue switches and current loops etc.

In the first embodiment the data transmitted between cells and between the first cell and the central battery monitoring systems varies between $V_{REF}^{i} \pm 5V$. The value

of 5 volts was chosen for convenience since the normal operating voltage for the microcontroller 31 is 5 volts above the ground voltage for that cell. Theoretically, where the data transmitted between cells is given by $V_{REF}^{i} \pm X$ volts, X must be greater than half the cell voltage V_{CELL} in order for the comparator to be able to regenerate the received data pulses at the increased or decreased potential. Practically, since the battery cells and the comparators are not ideal, X should be at least two and a half times the cell voltage V_{CELL}.

In the first embodiment, a cell monitoring device was used to monitor each cell of the battery. In a cheaper implementation, each cell monitoring device CM_i could be used to monitor two or three series connected battery cells C_i. However, in such an embodiment, where the data transmitted between cell monitoring device is given by $V_{REF}^{i} \pm X$ volts, X should be at least two and a half times the difference in the reference potentials between adjacent cell monitoring devices.

In the first embodiment, the received data pulses are compared with an approximation of the ground or reference voltage of the cell which sent the data pulses. Alternatively, the received data pulses could simply be compared with the reference voltage of the cell

monitoring device which receives the data pulses.

In the embodiments described, the cells are connected in series. It is possible to connect the battery cells C_i in a series-parallel or ladder configuration. Figure 10 shows such an interconnection of battery cells, in which cell C_{ia} is connected in parallel with cell C_{ib} and the parallel combinations C_{ia} and C_{ib} are connected in series for i = 1 to n. In the configuration shown in Figure 10, a single cell monitoring device CM_i is provided for monitoring each of the battery cells and the communication link 9 connects CM_{ia} to CM_{ib} and CM_{ib} to CM_{i+1a} etc. Alternatively, a single cell monitoring device could be used to monitor each parallel combination of battery cells C_{ia} and C_{ib}. Additionally, more than two battery cells can be connected in parallel.

In the above embodiments, the central battery monitoring and/or control system was provided at the zero volt reference voltage end of the communication link 9. Alternatively, the central battery monitoring and/or control system could be connected at the high reference voltage end of the communication link 9. Alternatively still, the central battery monitoring and/or control system could be connected at both ends, thereby forming a circular communications path in which messages which

are transmitted to and received from the battery monitoring/controlling system are passed in one direction through the cell monitoring/controlling devices. Therefore, each cell monitoring/controlling device only needs either an up-link or a down-link for increasing or decreasing the DC level of the received signals, depending on whether the messages are transmitted up or down the communication staircase.

In the above described embodiments, the communication link 9 comprised either one or two wires. As those skilled in the art will appreciate, the communication link 9 may comprise any number of wires along which data can be transmitted in parallel.

In the above embodiments, a separate central battery monitoring system or a central battery control system was provided. In an alternative embodiment, a combined battery monitoring and control system could be used to both monitor and control the battery.

In the above described embodiments, a single battery comprising a plurality of battery cells, is monitored and/or controlled by a central battery monitoring and/or controlling system. Figure 11 shows an alternative embodiment where a plurality of batteries B_i are provided, and wherein each battery B_i is monitored by its

own central battery monitoring system BM_i which communicates with a remote operator's terminal 151 via a data bus 153. The data bus 153 may be a proprietary data link or can be the public telephone exchange. In operation, each of the central battery monitoring systems BM_i monitors the respective battery B_i and reports its status back to the remote operator's terminal 151, where the condition of each of the batteries is monitored by a human operator. A similar system could also be provided for controlling or for monitoring and controlling a plurality of batteries.

Although the signalling system according to the present invention has been described in relation to an industrial battery, it can also be used in a system having a number of different circuits operating at different reference voltages for signalling between the different circuits.

The present invention is not limited by the exemplary embodiments described above, and various other modifications and embodiments will be apparent to those skilled in the art.

CLAIMS:

1. An apparatus for estimating the total working capacity of a battery, comprising:

means for charging the battery to a fully charged condition by supplying a charging current to said battery;

means for initiating a discharge of the battery by applying a load to the battery to thereby draw a discharge current from the battery;

means for monitoring the battery voltage and the level of said discharge current during the discharging of the battery and for outputting a signal when the battery voltage has reached a predefined minimum operating voltage indicative of the battery discharge limit;

means for terminating the discharging of the battery by removing said load from the battery when said signal is output by said monitoring means;

means for determining the period of time between the initiation and the termination of said battery discharging; and

means for estimating the total working capacity of the battery in dependence upon the level of said discharging current and said period of time.

2. An apparatus for estimating the total working

capacity of a battery, comprising:

a first input terminal for receiving a signal indicative of the current drawn from or supplied to the battery;

a second input terminal for receiving a signal indicative of the battery voltage;

means for causing the battery to discharge from a fully charged condition in which no more charge can be stored in the battery to a fully discharged condition in which the battery voltage has been reduced to a predefined minimum operating voltage;

means for determining the period of time during which said battery is discharged; and

means for estimating the total working capacity of the battery in dependence upon said period of time and upon the current drawn from the battery during said period of time.

3. An apparatus according to claim 1 or 2, wherein said estimating means estimates said total working capacity of the battery in dependence upon the product of said current and said period of time.

4. An apparatus according to any preceding claim, further comprising an input terminal for receiving sensor signals indicative of at least one sensed operating condition of the battery, and wherein said estimating

means estimates said total working capacity of the battery in dependence upon said sensor signals.

5. An apparatus according to claim 4, wherein said estimating means estimates said total working capacity of the battery in dependence upon a weighting factor indicative of the discharging efficiency of the battery for the at least one sensed operating condition.

6. An apparatus according to claim 5, comprising means for storing predefined efficiency characteristics of the battery for different operating conditions and means for determining said weighting factor in dependence upon the received sensor signals and the stored efficiency characteristics.

7. An apparatus according to claim 6, wherein said predefined efficiency characteristics of the battery relate the discharging efficiency of the battery to at least one of the ambient temperature and the level of the discharging current.

8. An apparatus according to any of claims 5 to 7, wherein said estimating means estimates said total working capacity (TCP) of the battery is in accordance with the following equation:

$$TCP = W_s . \int_0^{t_d} I(t)\, dt$$

where W_s represents said weighting factor, t_d is the period of time during which the battery is discharged and $I(t)$ is the current drawn from the battery during said period of time.

9. An apparatus for monitoring a battery, comprising:

a first input terminal for receiving an input signal indicative of the level of current drawn from or supplied to the battery;

a second input terminal for receiving an input signal indicative of the voltage of the battery; and

an apparatus according to any preceding claim for estimating the total working capacity of the battery.

10. An apparatus according to claim 9, further comprising means for estimating the remaining capacity of the battery.

11. An apparatus according to claim 10, wherein said remaining capacity estimating means estimates said remaining capacity as a percentage of the estimated total working capacity of the battery.

12. An apparatus according to claim 9 or 10, wherein

said means for estimating the remaining capacity of the battery operates periodically.

13. An apparatus according to claim 12, wherein said means for estimating the remaining capacity of the battery is operable (i) to monitor the level of current drawn from and/or supplied to the battery since the last estimate; and (ii) to estimate the change in capacity since the last estimate in dependence upon said monitored level of current and upon the period of time since the last estimate.

14. An apparatus according to claim 13, further comprising a third input terminal for receiving sensor signals indicative of at least one sensed operating condition of the battery, and wherein said remaining capacity estimating means estimates said change in capacity in dependence upon said sensor signals.

15. An apparatus according to claim 14, wherein said remaining capacity estimating means estimates said change in capacity in dependence upon a weighting factor indicative of the charging and/or discharging efficiency of the battery for the at least one sensed operating condition.

16. An apparatus according to claim 15, comprising means

for storing predefined efficiency characteristics of the battery for different operating conditions and means for determining said weighting factor in dependence upon said sensor signals and the stored efficiency characteristics.

17. An apparatus according to claim 16, wherein said predefined efficiency characteristics of the battery relate the charging and/or discharging efficiency of the battery to at least one of the ambient temperature and the level of the current drawn from or supplied to the battery.

18. An apparatus according to any of claims 14 to 17, wherein said remaining capacity estimating means estimates said remaining capacity (RCP) in accordance with the following equation:

$$RCP[i+1] = RCP[i] + \frac{100W_s . \int_0^{t_p} I(t)\ dt}{TCP}$$

where RCP[i] is the previous estimated value of the remaining capacity of the battery, W_s represents said weighting factor, t_p is the time interval since the last estimate of the remaining capacity of the battery, I(t) is the current drawn from and/or supplied to the battery since the last estimate and TCP is the estimate of the

total battery capacity.

19. An apparatus according to any of claims 9 to 18, wherein said apparatus for estimating the total working capacity of the battery is operable to estimate the total working capacity of the battery periodically.

20. An apparatus according to claim 19, further comprising means for maintaining a record of previous estimates of the total working capacity of the battery.

21. An apparatus according to claim 20, further comprising means for predicting the battery end of life and/or future faults in dependence upon said record of previous estimates of the total working capacity of the battery.

22. An apparatus according to any of claims 9 to 21, comprising a power input terminal for receiving power from the battery which the apparatus is to monitor.

23. An apparatus according to any of claims 9 to 22, further comprising means for determining the internal resistance of the battery.

24. A method of estimating the total working capacity of a battery, the method comprising the steps of:

causing the battery to discharge from a fully charged condition in which no more charge can be stored in the battery to a fully discharged condition in which the battery voltage has been reduced to a predefined minimum operating voltage;

determining the period of time during which the battery is discharged; and

estimating the total working capacity of the battery in dependence upon said period of time and upon the current drawn from the battery during said period of time.

25. A method of estimating the remaining capacity of a battery comprising the steps of:

monitoring the level of current drawn from and/or supplied to the battery since the last estimate;

estimating the change in capacity since the last estimate in dependence upon said monitored level of current and upon the period of time since the last estimate; and

adding the change in capacity since the last estimate to the last estimate.

26. A method according to claim 25, wherein prior to said monitoring step, the method further comprises the steps of:

initially charging the battery to a fully charged

condition;

using the method according to claim 24 to estimate the total working capacity of the battery;

recharging the battery to said fully charged condition; and

setting the initial estimate of the remaining capacity of the battery to equal the estimated total working capacity of the battery.

27. A signalling system for use with a plurality of series connected battery cells, comprising:

a plurality of cell signalling devices, each to be powered by a respective one or more of said plurality of battery cells; and

a communication link connecting said plurality of cell signalling devices in series, such that the position of each cell signalling device in said series communication link corresponds with the position of the cell or cells which are to power the cell signalling device, in said series connection of battery cells;

wherein at least one of said cell signalling devices comprises a DC level shift circuit which is operable (i) to receive signals transmitted from an adjacent cell signalling device; (ii) to shift the DC level of the received signals; and (iii) to output the level shifted signals for transmission to said communication link.

28. A signalling system according to claim 27, wherein said DC level shift circuit is operable (i) to receive signals from an adjacent cell signalling device which is to be powered by a cell having a higher ground potential than that of the receiving cell signalling device; (ii) to decrease the DC level of the received signals; and (iii) to output the level shifted signals for transmission to said communication link.

29. A signalling system according to claim 27, wherein said DC level shift circuit is operable (i) to receive signals from an adjacent cell signalling device which is to be powered by a cell having a lower ground potential than that of the receiving cell signalling device; (ii) to increase the DC level of the received signals; and (iii) to output the level shifted signals for transmission to said communication link.

30. A signalling system according to any of claims 27 to 29, wherein each cell signalling device comprises at least one sensor input terminal operable to receive a signal from a sensor, which signal is indicative of a condition of the cell or cells which are to power the cell signalling device.

31. A signalling system according to claim 30, wherein each of said cell signalling devices comprises a sensor

input terminal operable to receive a signal from an electrolyte level and/or electrolyte PH sensor, which signal is indicative of the electrolyte level and/or the electrolyte PH of the cell or cells which are to power the cell signalling device.

32. A signalling system according to claim 30 or 31, wherein each cell signalling device comprises a sensor input terminal operable to receive a signal from a voltage sensor, which signal is indicative of the voltage of the cell or cells which are to power the cell signalling device.

33. A signalling system according to any of claims 30 to 32, wherein each cell signalling device comprises a sensor input terminal which is operable to receive a signal from a temperature sensor, which signal is indicative of the temperature of the cell or cells which are to power the cell signalling device.

34. A signalling system according to any of claims 30 to 33, wherein each cell signalling device comprises a sensor input terminal operable to receive a signal from a voltage interconnection sensor, which signal is indicative of the voltage drop between the cell which is to power said cell signalling device and its adjacent cells.

35. A signalling system according to any of claims 27 to 34, wherein each cell signalling device comprises two of said DC level shift circuits, one of which is operable (i) to receive signals from an adjacent cell signalling device which is to be powered by a cell having a higher ground potential than that of the receiving cell signalling device; (ii) to decrease the DC level of the received signals; and (iii) to output the level shifted signals for transmission to said communication link; and the other one of which is operable (i) to receive signals from an adjacent cell signalling device which is to be powered by a cell having a lower ground potential than that of the receiving cell signalling device; (ii) to increase the DC level of the received signals; and (iii) to output the level shifted signals for transmission to said communication link.

36. A signalling system according to claim 35, wherein said communication link comprises a single wire communication bus, and wherein said two DC level shift circuits lie on two separate data transfer paths which are connectable to said single wire communication bus by a switch.

37. A signalling system according to claim 35, wherein said two DC level shift circuits are located on separate data transfer paths, and wherein said communication link

comprises a two wire communication bus for connecting the respective data transfer paths with corresponding data transfer paths of an adjacent cell signalling device.

38. A signalling system according to claim 35, wherein said communication link comprises a multi-wire communication bus, whereby plural data signals can be transmitted along said communication link at the same time.

39. A signalling system according of claims 27 to 38, further comprising a central battery monitoring system for monitoring the battery as a whole, and wherein each of said cell signalling devices is operable to communicate, via said communication link, with said central battery monitoring system.

40. A signalling system according to claim 39, wherein each cell signalling device comprises:

at least one sensor input terminal operable to receive a signal from a sensor, which signal is indicative of a condition of the cell or cells which are to power the cell signalling device; and

a signal generator operable to generate a signal in dependence upon said sensor signal and to output said generated signal for transmission to said central battery monitoring system.

the battery which it is to monitor.

45. A signalling system according to any of claims 40 to 44, wherein said central battery monitoring system is operable to communicate the monitoring results to a remote user.

46. A signalling system according to any of claims 40 to 45, wherein said central battery monitoring system is operable to monitor the battery voltage, the battery temperature, the total battery current and the total level of charge.

47. A signalling system according to any of claims 39 to 46, wherein said central battery monitoring system comprises:

a first input terminal for receiving a signal indicative of the current drawn from or supplied to the battery;

a second input terminal for receiving a signal indicative of the battery voltage;

means for discharging the battery from a fully charged condition in which no more charge can be stored in the battery to a fully discharged condition in which the battery voltage has been reduced to a predefined minimum operating voltage;

means for determining the period of time during

41. A signalling system according to claim 40, wherein said central battery monitoring system is operable to poll each of said plurality of cell signalling devices in turn, and wherein upon being polled, each cell signalling device is operable to return a signal back to said central battery monitoring system via said communication link, which is indicative of said condition of the cell which is to power said cell signalling device.

42. A signalling system according to claim 40 or 41, wherein said condition is the cell voltage and wherein said central battery monitoring system is operable to measure the battery charging and discharging current and to calculate the internal resistance of each battery cell by correlating said charging and discharging current with the cell voltages determined by the respective cell signalling devices.

43. A signalling system according to any of claims 40 to 42, wherein said central battery monitoring system is operable to store information concerning the status of the battery cells in a removable storage medium.

44. A signalling system according to any of claims 40 to 43, wherein said central battery monitoring system is operable to sound an alarm upon detection of a fault with

which said battery is discharged; and

means for estimating the total working capacity of the battery in dependence upon said period of time and upon the current drawn from said battery during said period of time.

48. A signalling system according to claim 47, wherein said estimating means estimates said total working capacity of the battery in dependence upon the product of the level of said discharging current and said period of time.

49. A signalling system according to claim 47 or 48, wherein said central battery monitoring system further comprises an input terminal for receiving sensor signals indicative of at least one sensed operating condition of the battery, and wherein said estimating means estimates said total working capacity of the battery in dependence upon said sensor signals.

50. A signalling system according to claim 49, wherein said estimating means estimates said total working capacity of the battery in dependence upon a weighting factor indicative of the discharging efficiency of the battery for the at least one sensed operating condition.

51. A signalling system according to claim 50, wherein

said central battery monitoring system further comprises means for storing predefined efficiency characteristics of the battery for different operating conditions and means for determining said weighting factor in dependence upon the received sensor signals and the stored efficiency characteristics.

52. A signalling system according to claim 51, wherein said predefined efficiency characteristics of the battery relate the discharging efficiency of the battery to at least one of the ambient temperature and the level of the discharging current.

53. A signalling system according to any of claims 50 to 52, wherein said estimating means estimates said total working capacity (TCP) of the battery is in accordance with the following equation:

$$TCP = W_s . \int_0^{t_d} I(t)\ dt$$

where W_s represents said weighting factor, t_d is the period of time during which the battery is discharged and $I(t)$ is the current drawn from the battery during the discharging period.

54. A signalling system according to any of claims 47 to 53, wherein said central battery monitoring system

further comprises means for estimating the remaining capacity of the battery.

55. A signalling system according to claim 54, wherein said remaining capacity estimating means estimates said remaining capacity as a percentage of the estimated total working capacity of the battery.

56. A signalling system according to claim 54 or 55, wherein said means for estimating the remaining capacity of the battery operates periodically.

57. A signalling system according to claim 56, wherein said means for estimating the remaining capacity of the battery is operable (i) to monitor the level of current drawn from and/or supplied to the battery since the last estimate; and (ii) to estimate the change in capacity since the last estimate in dependence upon the current drawn from and/or supplied to the battery since the last estimate and the period of time since the last estimate.

58. A signalling system according to claim 57, wherein said central battery monitoring system comprises an input terminal for receiving sensor signals indicative of at least one sensed operating condition of the battery, and wherein said remaining capacity estimating means estimates said change in capacity in dependence upon said

sensor signals.

59. A signalling system according to claim 58, wherein said remaining capacity estimating means estimates said change in capacity in dependence upon a weighting factor indicative of the charging and/or discharging efficiency of the battery for the at least sensed operating condition.

60. A signalling system according to claim 59, comprising means for storing predefined efficiency characteristics of the battery for different operating conditions and means for determining said weighting factor in dependence upon said sensor signals and the stored efficiency characteristics.

61. A signalling system according to claim 60, wherein said predefined efficiency characteristics of the battery relate the charging and/or discharging efficiency of the battery to at least one of the ambient temperature and the level of the current drawn from or supplied to the battery.

62. A signalling system according to any of claims 58 to 61, wherein said remaining capacity estimating means estimates said remaining capacity (RCP) in accordance with the following equation:

$$RCP[i+1] = RCP[i] + \frac{100W_s \cdot \int_0^{t_p} I(t)\ dt}{TCP}$$

where RCP[i] is the previous estimated value of the remaining capacity of the battery, W_s represents said weighting factor, t_p is the time interval since the last estimate of the remaining capacity of the battery, I(t) is the current drawn from and/or supplied to the battery since the last estimate and TCP is the estimate of the total battery capacity.

63. A signalling system according to any of claims 47 to 62, wherein said means for estimating the total working capacity of the battery is operable to estimate the total working capacity of the battery periodically.

64. A signalling system according to claim 63, wherein said central battery monitoring system further comprises means for maintaining a record of previous estimates of the total working capacity of the battery.

65. A signalling system according to claim 64, wherein said central battery monitoring system further comprises means for predicting the battery end of life and/or future faults in dependence upon said record of previous

estimates of the total working capacity of the battery.

66. A signalling system according to any of claims 47 to 65, wherein said central battery monitoring system comprises a power input terminal for receiving power from the battery which the central battery monitoring system is to monitor.

67. A signalling system according to any of claims 47 to 66, wherein said central battery monitoring system further comprises means for determining the internal resistance of the battery as a whole.

68. A signalling system according to any of claims 27 to 67, wherein each of said cell signalling devices is operable to receive a control signal from said communication link and comprises a signal generator operable to generate an actuation signal in dependence upon said received control signal and to output said generated actuation signal for controlling an actuator.

69. A signalling system according to claim 68, further comprising a central battery control system for transmitting said control signal to said communication link.

70. A signalling system according to claim 69, wherein

said central battery control system is operable to transmit said control signal to each of said cell signalling devices in turn.

71. A signalling system according to any of claims 68 to 70, wherein each cell signalling device comprises a sensor input terminal operable to receive a signal from an electrolyte level and/or electrolyte PH sensor, which signal is indicative of the electrolyte level and/or the electrolyte PH of the cell or cells which are to power the cell signalling device, and wherein upon receiving said control signal said cell signalling device is operable to output an actuation signal in dependence upon said sensor signal for controlling the addition of water and acid to the cell in order to control its electrolyte level and/or its electrolyte PH.

72. A signalling system according to any of claims 68 to 70, wherein said actuation signal is for controlling a display.

73. A signalling system according to claim 40 or 68 or any claim dependent thereon, wherein said signal generator comprises a microcontroller which is operable to receive communications from and to transmit communications to said communication link.

74. A signalling system according to claim 73, wherein the microcontrollers of said signalling devices are independently addressable so that communications can be directed to a selected one or more of said cell signalling devices via said communication link.

75. A signalling system according to claim 74, wherein the microcontrollers of said cell signalling devices are operable to communicate with each other.

76. A signalling system according to any of claims 27 to 75, wherein said DC level shift circuit comprises a comparator.

77. A signalling system according to claim 76, wherein said comparator comprises a voltage comparator.

78. A signalling system according to claim 77, wherein the communications transmitted over said communication link comprise square wave signals, and wherein each of said comparators is arranged to compare said square wave signals with a reference signal which is an approximation of the ground potential of the adjacent cell signalling device which transmitted the received square wave signals and to output a square wave signal in dependence upon whether or not the received square wave signal is greater or less than said reference signal.

79. A signalling system according to claim 78, wherein said comparator is operable to output a square wave voltage which varies between $X_{REF}^{i} \pm X$ volts, where X_{REF}^{i} is the ground or reference potential of the receiving cell signalling device and X is greater than half the cell voltage of the cell which is to power the cell signalling device.

80. A signalling system according to claim 79, wherein X is at least two and a half times the cell voltage of the cell which is to power the cell signalling device.

81. A signalling system according to claim 76, wherein said comparator comprises a current comparator.

82. A signalling system according to claim 76, wherein alternate voltage to current comparators and current to voltage comparators are used in adjacent cell signalling devices.

83. A signalling system according to any of claims 27 to 75, wherein said DC level shift circuit comprises a solid state analogue switch or one or more current loops.

84. A signalling system according to any of claims 27 to 83, wherein each cell signalling device comprises a DC to DC convertor which is operable to convert the cell

voltage of the cell which is to power the cell signalling device, to supply voltages and a ground voltage for powering the cell signalling device.

85. A signalling system according to any of claims 27 to 84, wherein a cell signalling device is provided for each of said series connected battery cells.

86. A signalling system according to any of claims 27 to 85, wherein one or more of said series connected battery cells are connected in parallel with one or more additional battery cells.

87. A cell signalling device for use in a signalling system according to any of claims 27 to 86, comprising:

a power input terminal connectable to the cell or cells which is or are to power said cell signalling device; and

at least one DC level shift circuit which is operable (i) to receive signals transmitted from an adjacent cell signalling device; (ii) to shift the DC level of the received signals; and (iii) to output the level shifted signals for transmission to the communication link forming part of said signalling system.

88. A cell signalling device having the cell signalling

device features of any of claims 27 to 86.

89. A signalling kit for use in a signalling system according to any of claims 27 to 86, comprising a plurality of cell signalling devices according to claim 87 or 88.

90. A signalling kit according to claim 89, further comprising a communication link for connecting said plurality of cell signalling devices in series.

91. A signalling system according to any of claims 27 to 86 in combination with a plurality of series connected battery cells, wherein one or more of said battery cells are connected to a respective one of said plurality of cell signalling devices, for powering said cell signalling devices.

92. A cell signalling device according to claim 87 or 88 in combination with a battery cell, wherein the terminals of said battery cell are connectable to said cell signalling device.

93. A signalling method using a plurality of series connected battery cells, comprising the steps of:

providing a plurality of cell signalling devices and powering them with a respective one or more of said

plurality of battery cells;

providing a communication link which connects said plurality of cell signalling device in series such that the position of each cell signalling device in the series corresponds with the position of the cell which is to power the cell signalling device, in the series connection of battery cells;

receiving signals transmitted from an adjacent cell signalling device;

shifting the DC level of the received signals; and

outputting the level shifted signals to the communication link.

94. A signalling system for use with a plurality of systems each operating at a different reference voltage, comprising:

a plurality of signalling devices, each to be powered by a respective one or more of said plurality of systems; and

a communication link connecting said plurality of signalling devices;

wherein at least one of said signalling devices comprises a DC level shift circuit which is operable (i) to receive signals transmitted from another signalling device; (ii) to shift the DC level of the received signals; and (iii) to output the level shifted signals for transmission to said communication link.

ABSTRACT:

SIGNALLING SYSTEM

A battery signalling system is provided which can be used to monitor and/or control a battery 1 having a number of series connected battery cells C_i. When used to monitor the battery cells, The battery signalling system can comprise a central battery monitoring system 3 for monitoring the industrial battery 1 as a whole, a number of cell monitoring devices CM_i for monitoring one or more battery cells C_i and a communication link 9 for connecting the cell monitoring devices CM_i in series in a daisy chain configuration to the central battery monitoring system 3. In operation, the central battery monitoring system 3 can poll each of the cell monitoring devices CM_i in turn and analyse the data received from a polled cell monitoring device CM_i to detect malfunctions and/or under performing cells.

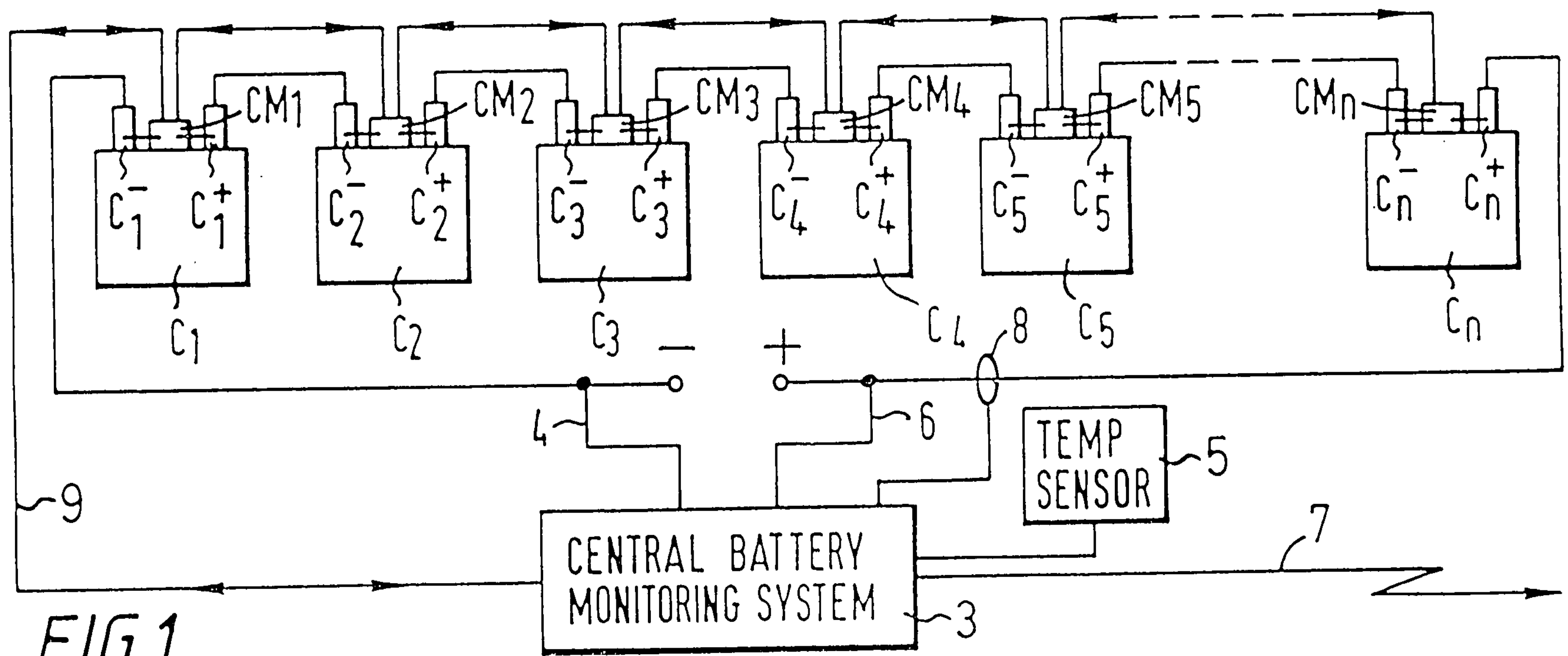

CM1
CM2
CM3
CM4
CM5
CMn
C_1^- C_1^+
C_2^- C_2^+
C_3^- C_3^+
C_4^- C_4^+
C_5^- C_5^+
C_n^- C_n^+
C_1
C_2
C_3
C_4
C_5
C_n
1
−
+
4
6
8
TEMP SENSOR
5
9
7
CENTRAL BATTERY MONITORING SYSTEM
3

FIG.1

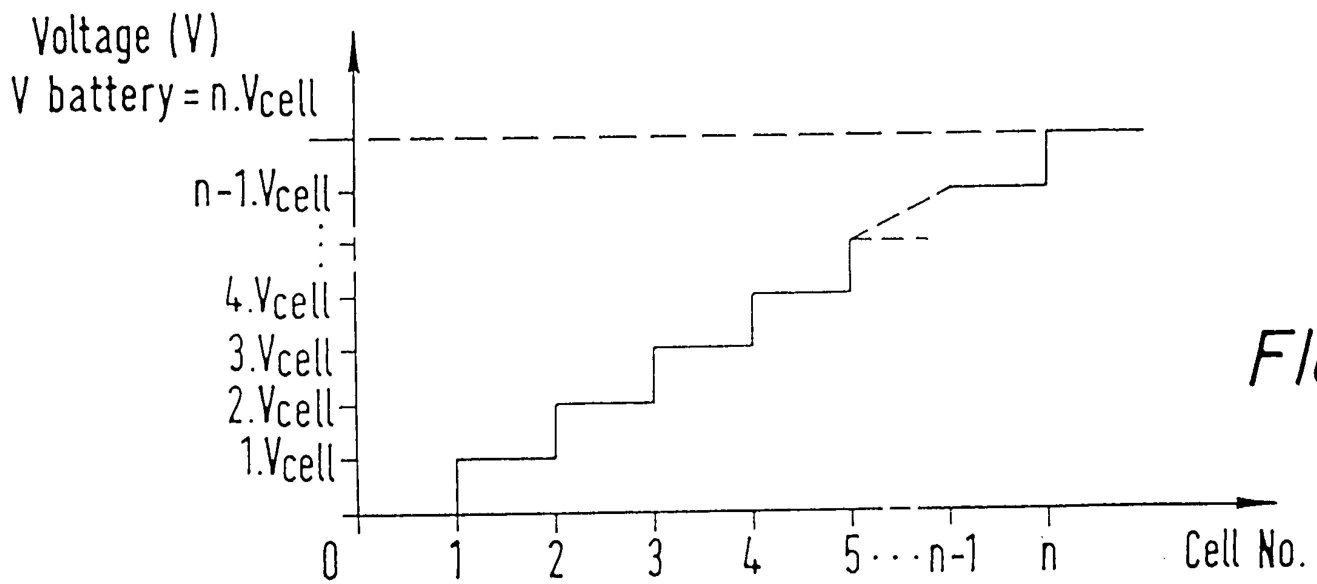

Voltage (V)
V battery = n.Vcell
n-1.Vcell
4.Vcell
3.Vcell
2.Vcell
1.Vcell
0
1
2
3
4
5 · · · n-1
n
Cell No.

FIG.4

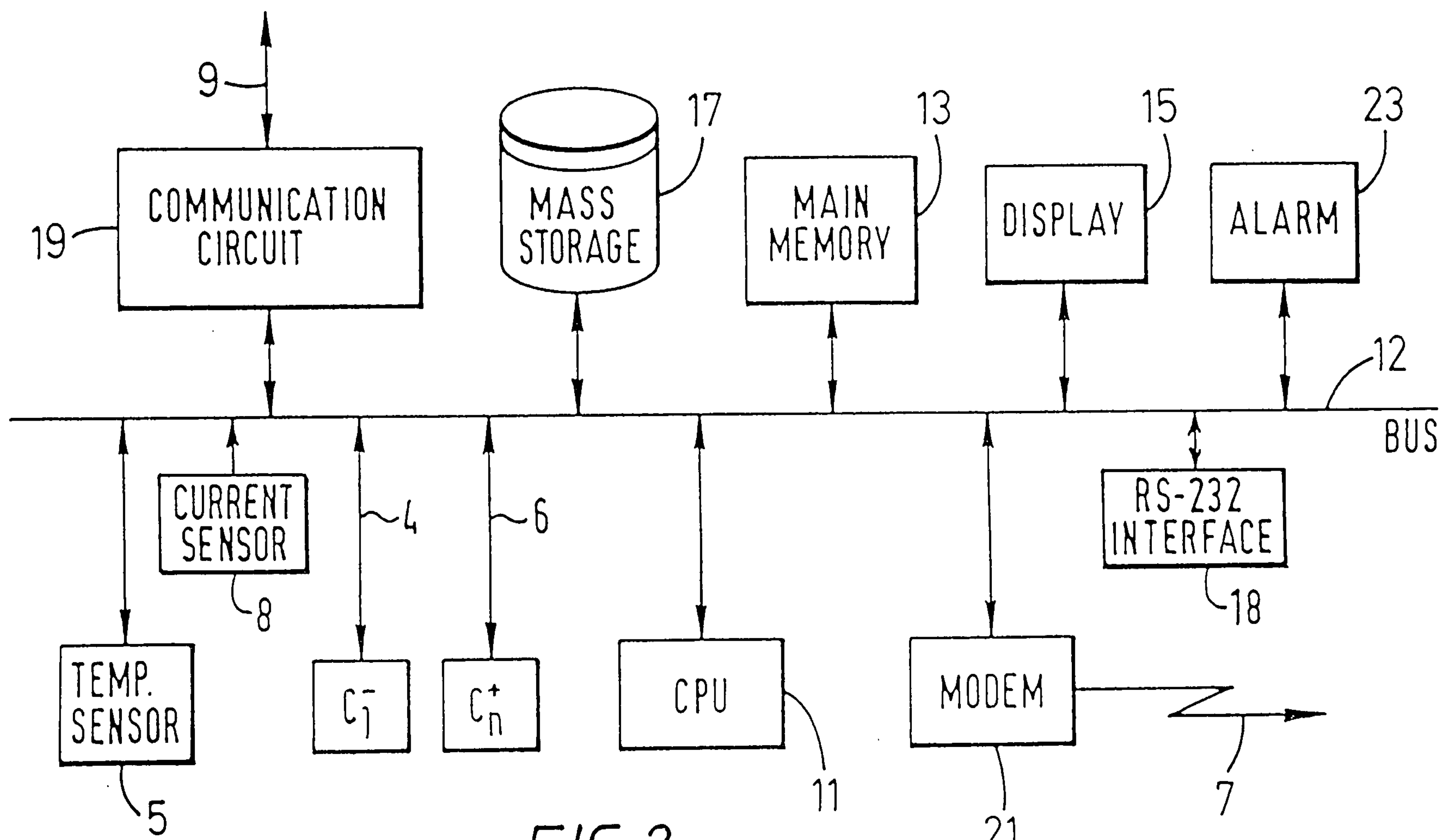
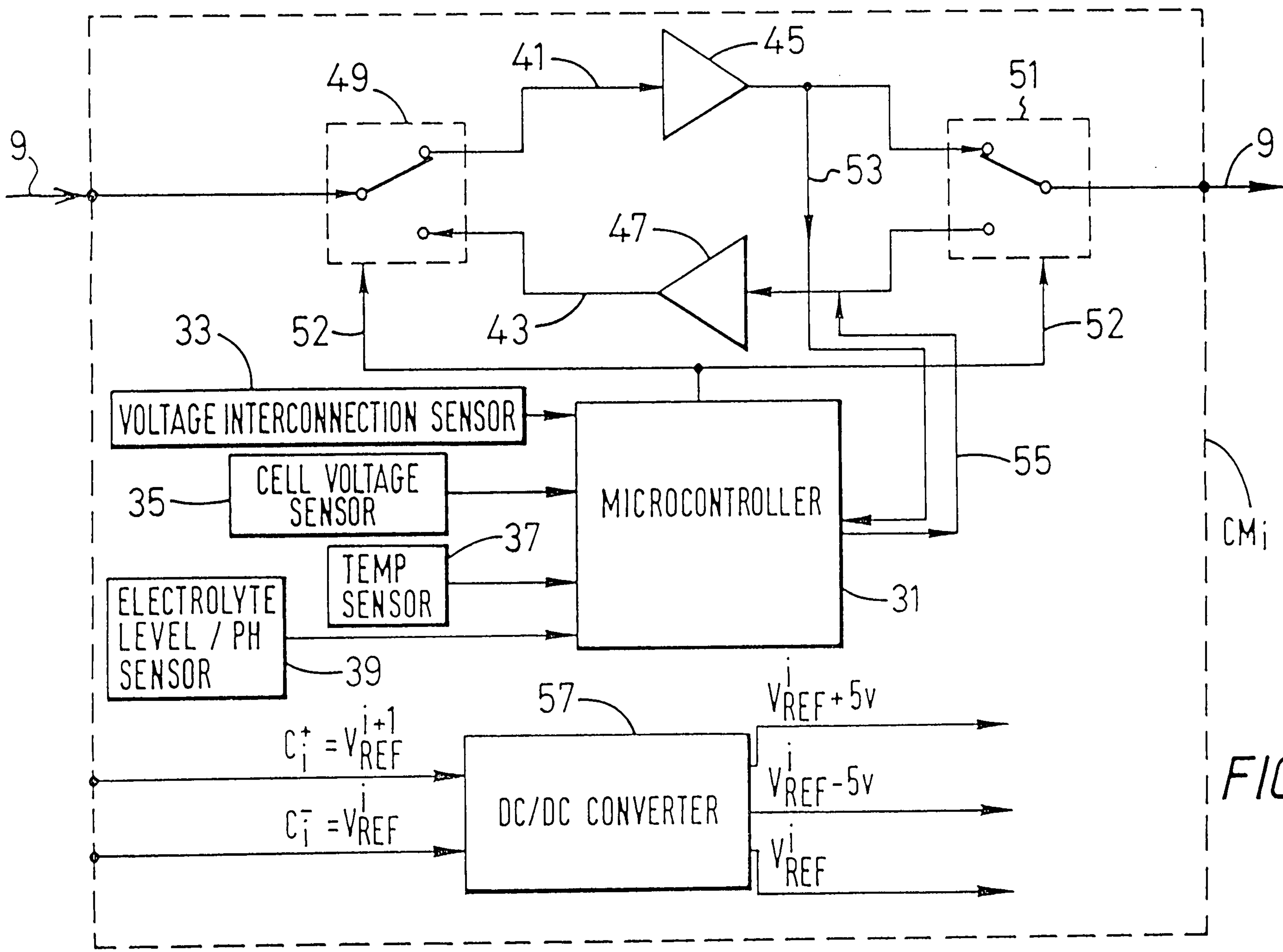

COMMUNICATION CIRCUIT
19
9
MASS STORAGE
17
MAIN MEMORY
13
DISPLAY
15
ALARM
23
12
BUS
CURRENT SENSOR
8
TEMP. SENSOR
5
C_1^-
4
C_n^+
6
CPU
11
MODEM
21
7
RS-232 INTERFACE
18

FIG. 2



9
49
41
45
51
9
53
47
43
52
52
33
VOLTAGE INTERCONNECTION SENSOR
35
CELL VOLTAGE SENSOR
37
TEMP SENSOR
ELECTROLYTE LEVEL / PH SENSOR
39
MICROCONTROLLER
55
31
CMi
57
DC/DC CONVERTER
$C_i^+ = V_{REF}^{i+1}$
$C_i^- = V_{REF}^{i}$
$V_{REF}^{i} + 5v$
$V_{REF}^{i} - 5v$
V_{REF}^{i}

FIG.3

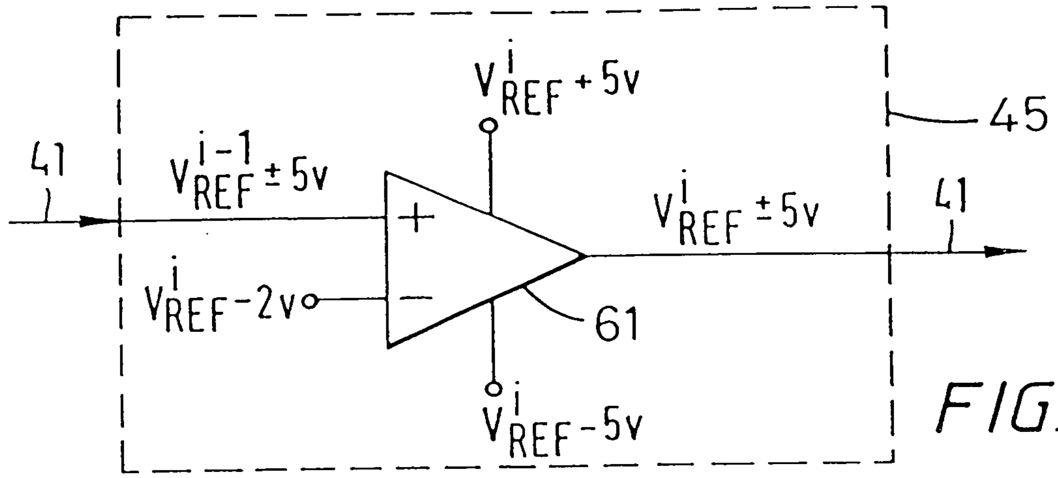


FIG. 5a

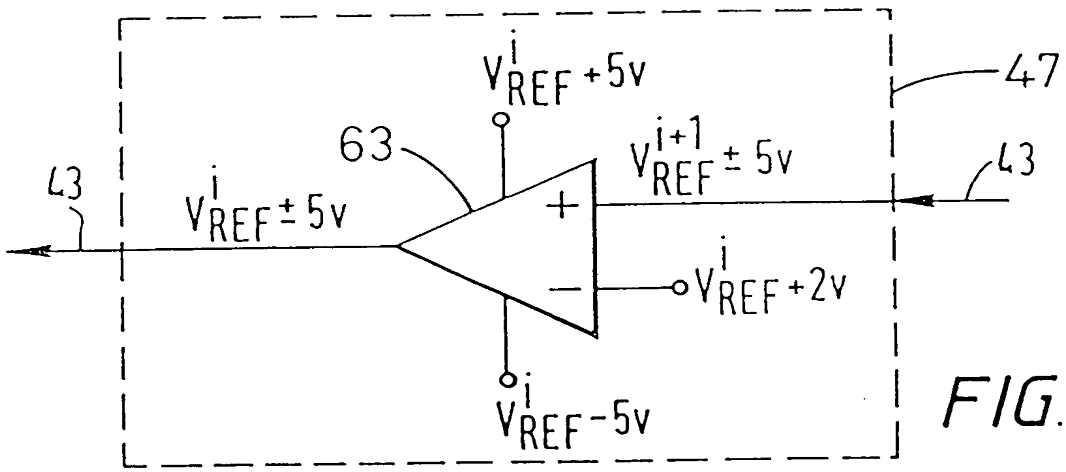


FIG. 5b

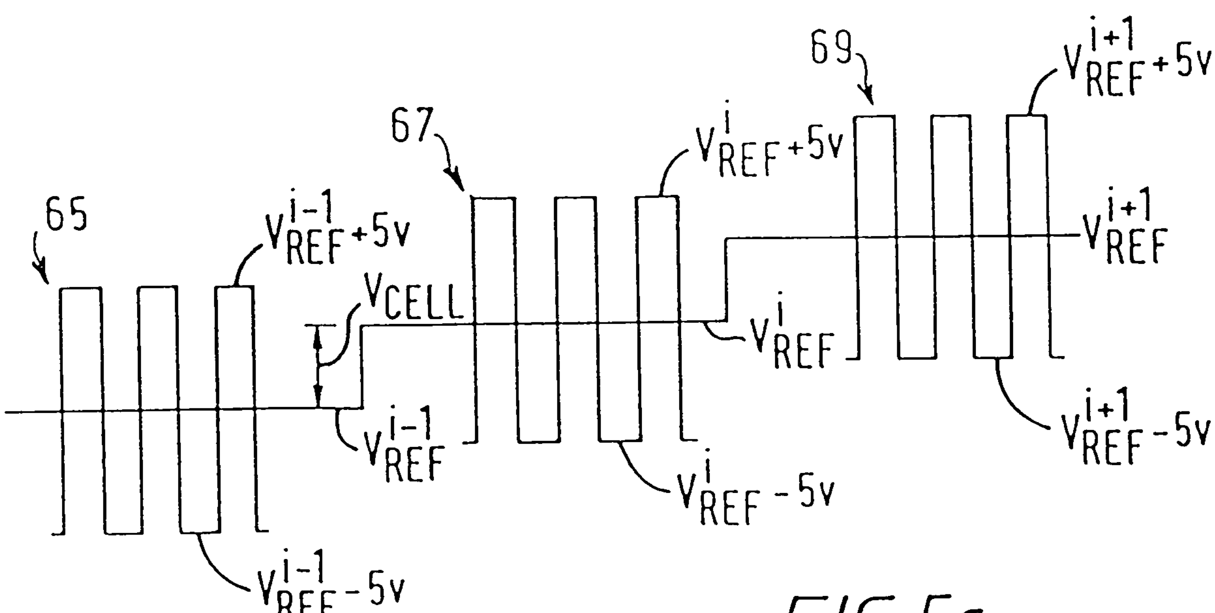


FIG. 5c

FIG. 6

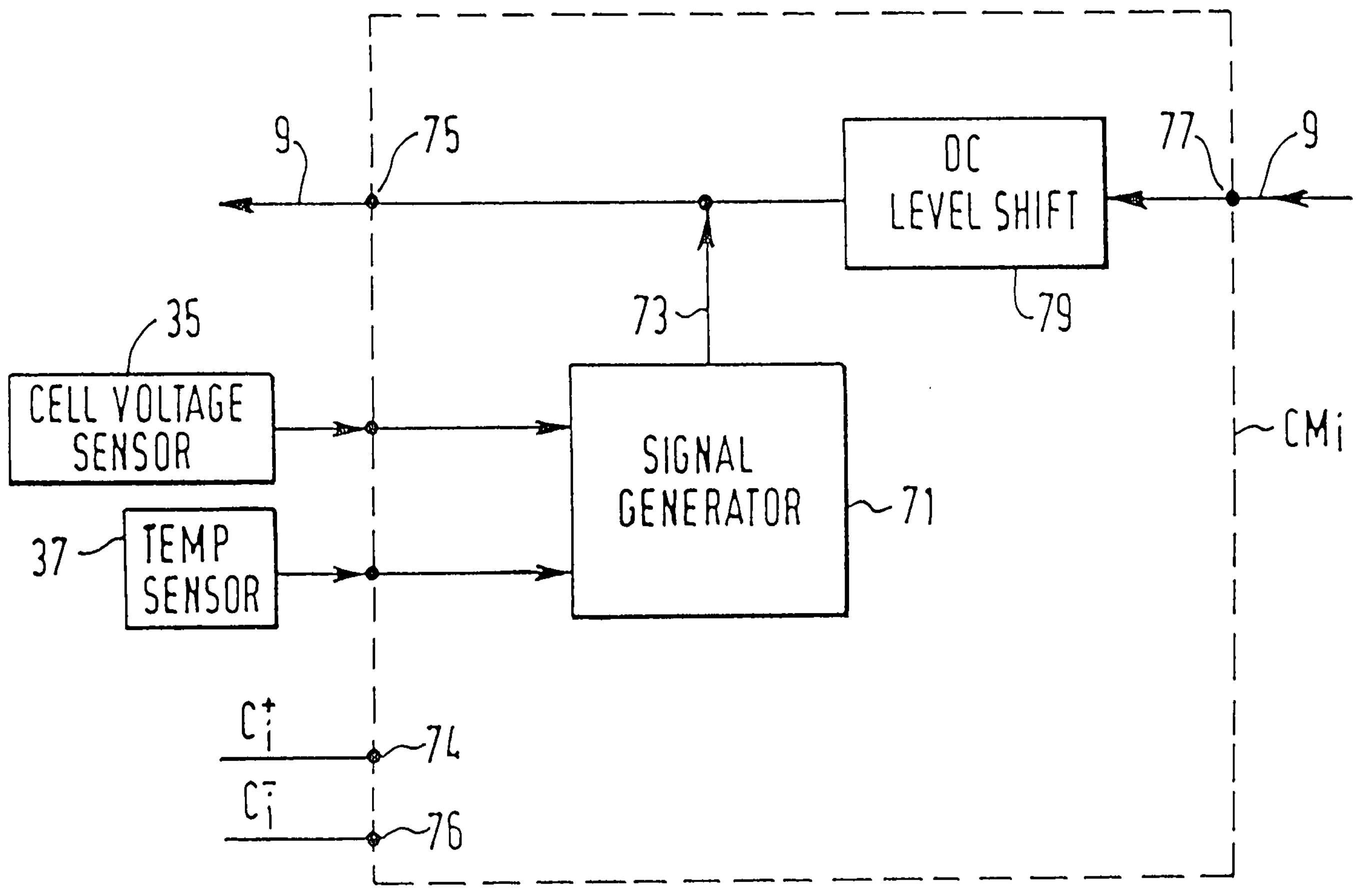
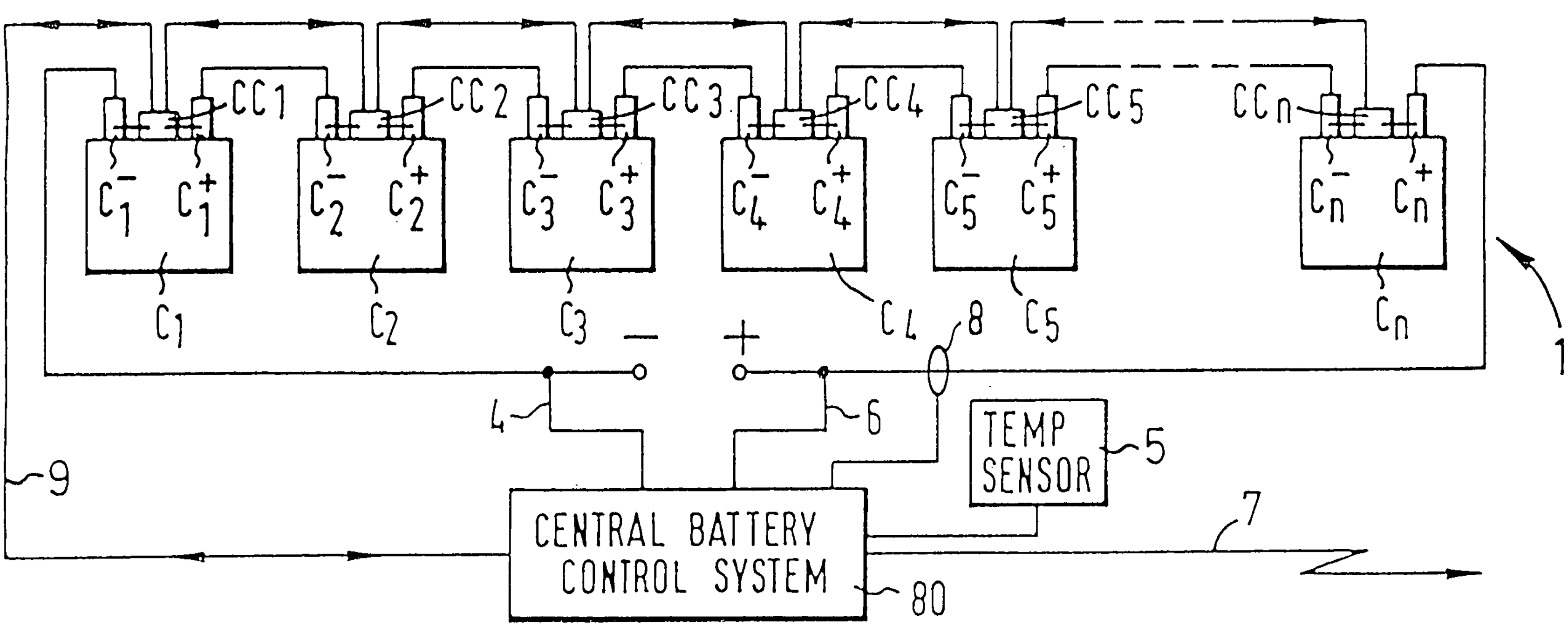
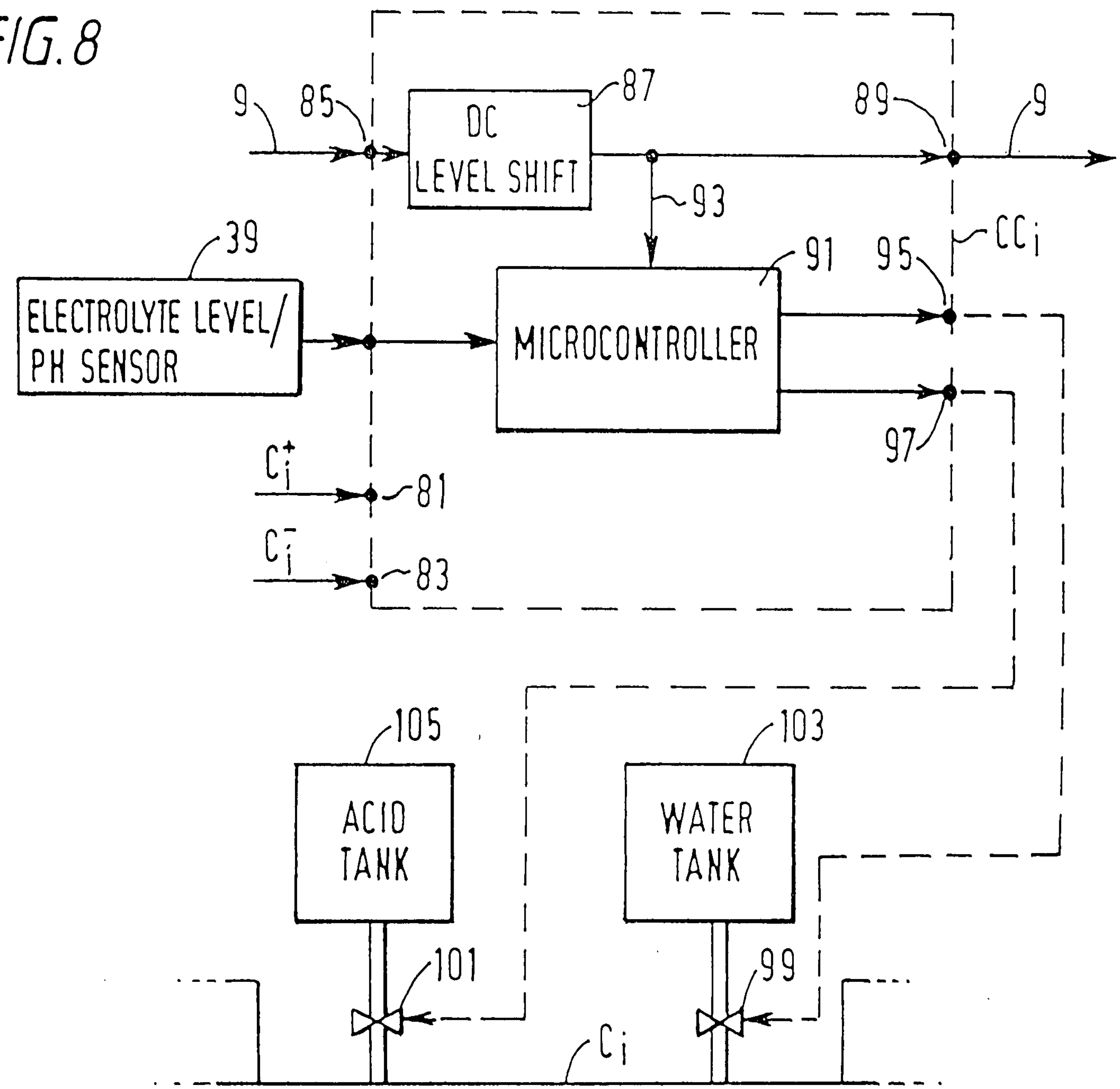

9
75
DC
LEVEL SHIFT
77
9
79
35
73
CELL VOLTAGE
SENSOR
SIGNAL
GENERATOR
CMi
71
37
TEMP
SENSOR
C_i^+
74
C_i^-
76

FIG. 7



CC1
CC2
CC3
CC4
CC5
CCn
C_1^- C_1^+
C_2^- C_2^+
C_3^- C_3^+
C_4^- C_4^+
C_5^- C_5^+
C_n^- C_n^+
C_1
C_2
C_3
C_4
C_5
C_n
−
+
1
4
6
8
9
TEMP SENSOR
5
7
CENTRAL BATTERY CONTROL SYSTEM
80

FIG. 8


9
85
DC
LEVEL SHIFT
87
89
9
93
39
ELECTROLYTE LEVEL/
PH SENSOR
MICROCONTROLLER
91
95
CC$_i$
97
C$_i^+$
81
C$_i^-$
83
105
ACID
TANK
103
WATER
TANK
101
99
C$_i$

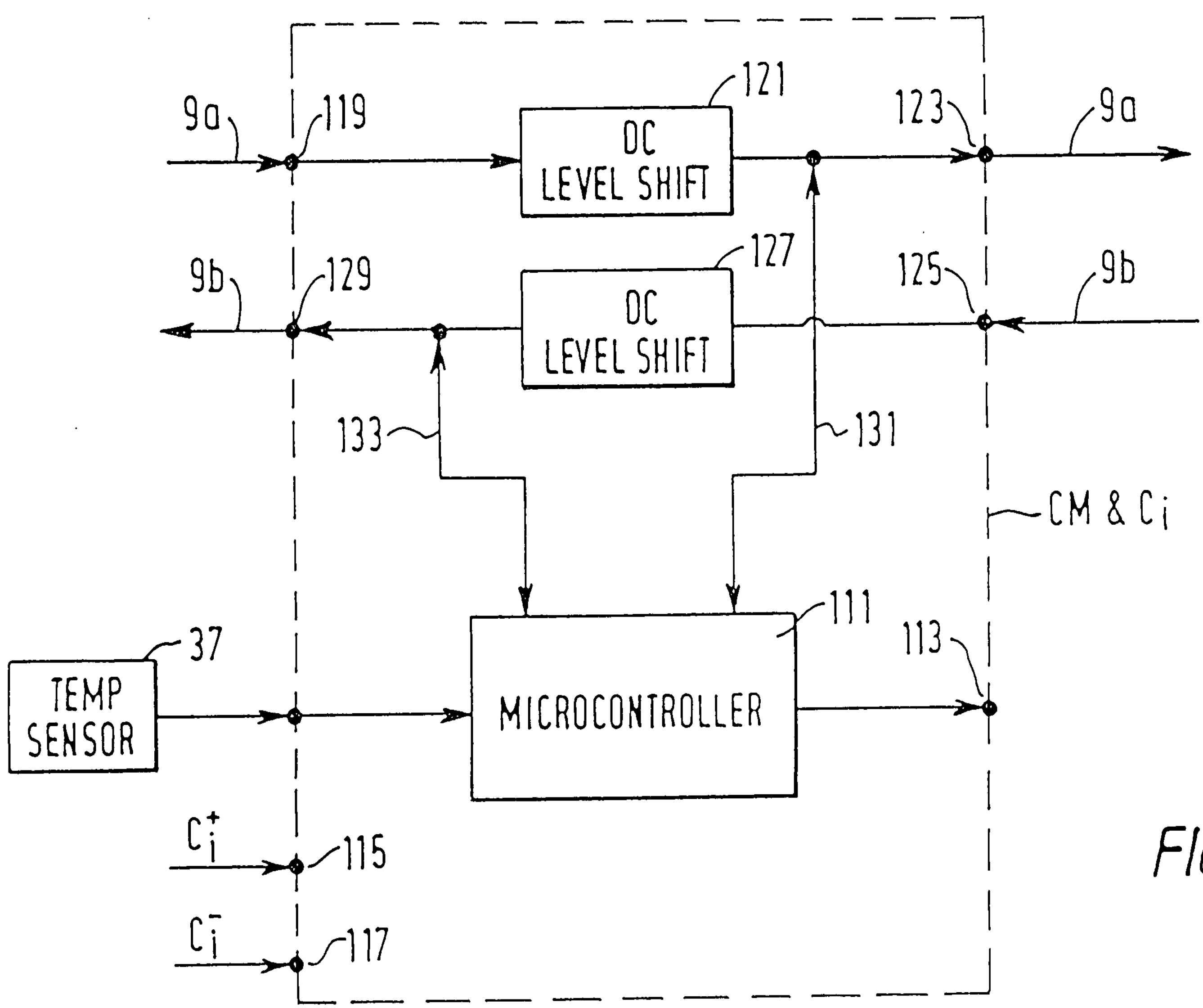

9a
119
121
DC
LEVEL SHIFT
123
9a
9b
129
127
DC
LEVEL SHIFT
125
9b
133
131
CM & Ci
37
TEMP
SENSOR
111
MICROCONTROLLER
113
C_i^+
115
C_i^-
117

FIG. 9

FIG.10

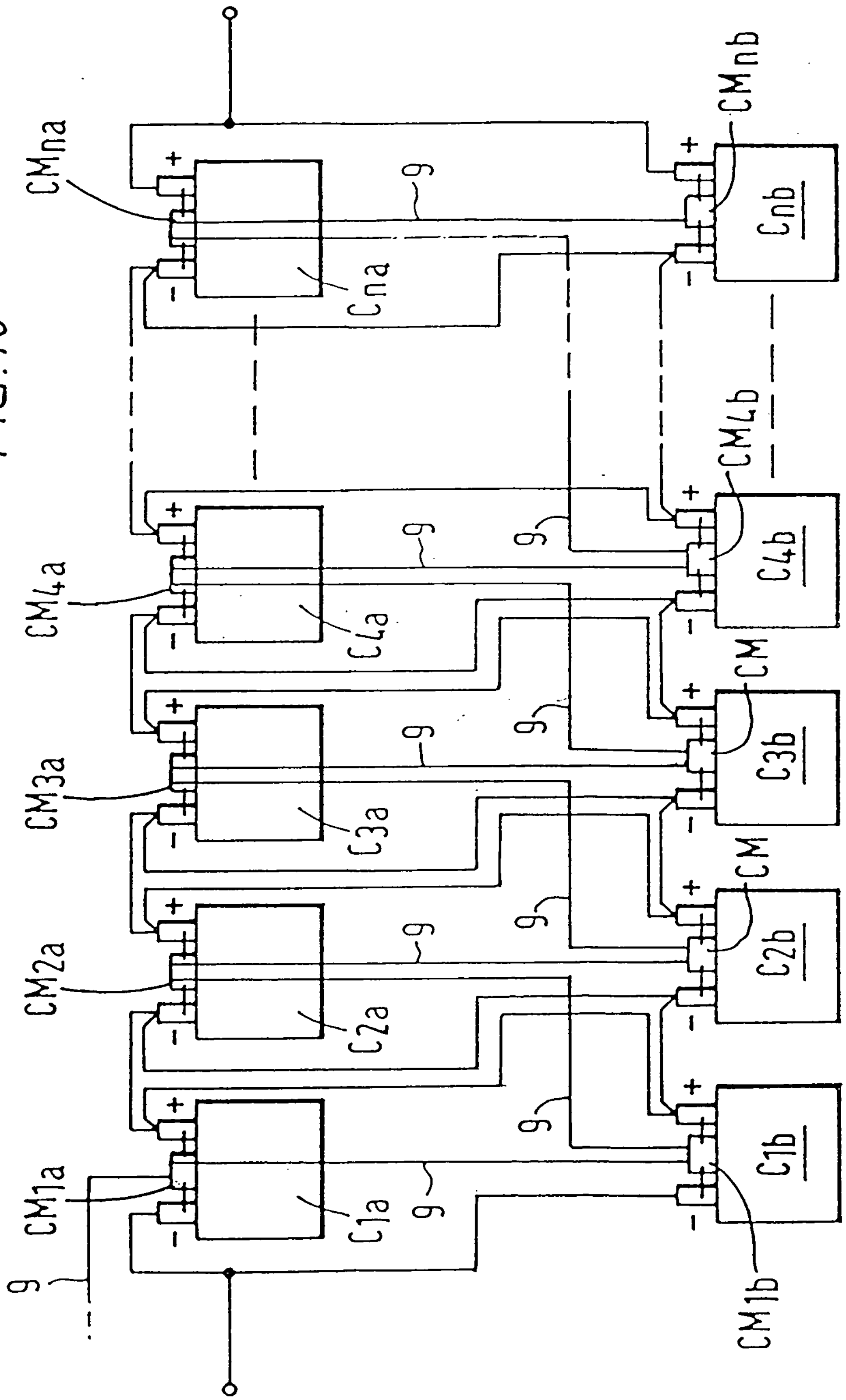
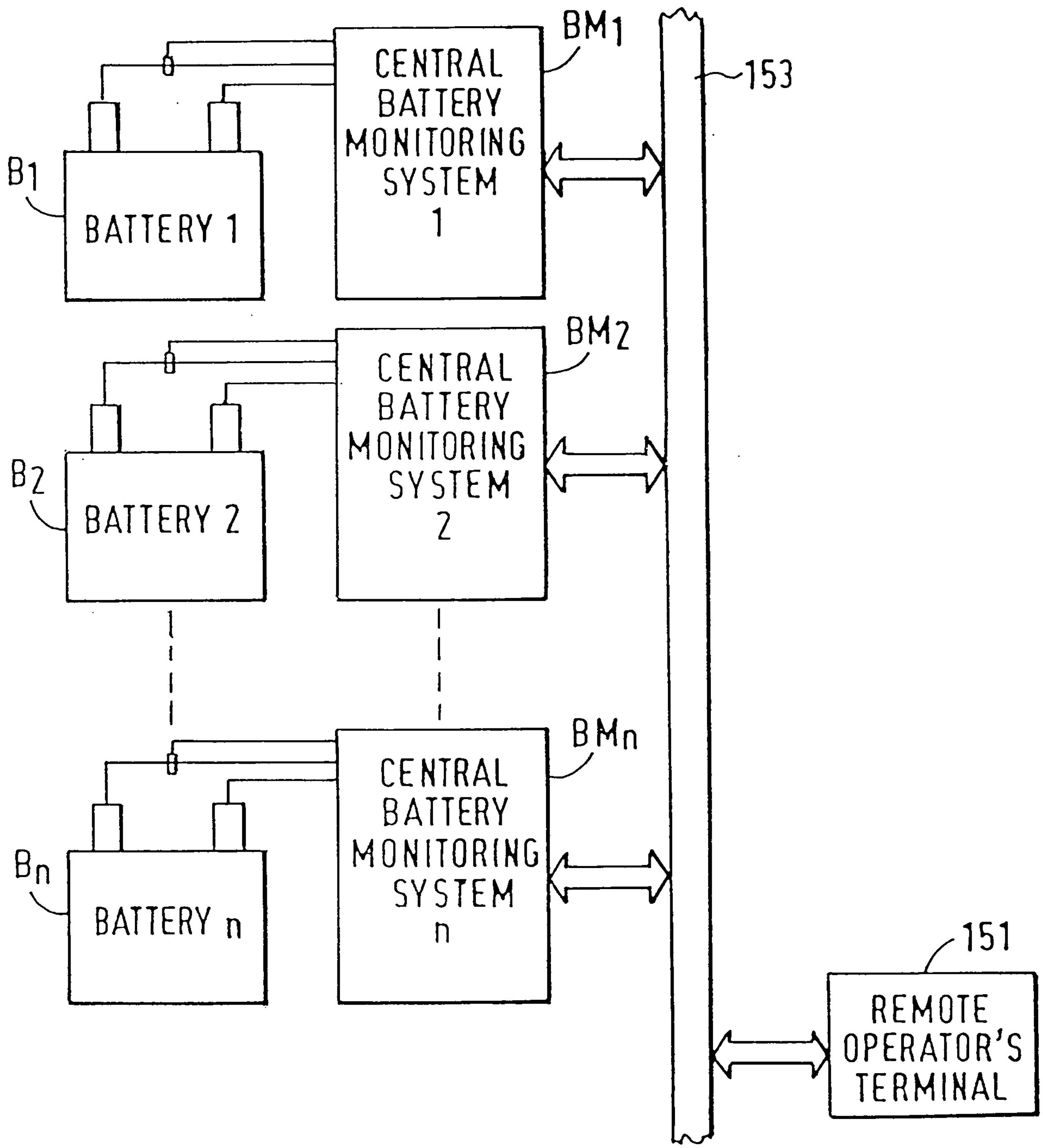

CMna
Cna
CMnb
Cnb
CM4a
C4a
CM4b
C4b
CM3a
C3a
CM
C3b
CM2a
C2a
CM
C2b
CM1a
C1a
CM1b
C1b
9
+
-

FIG. 11


BM1
153
CENTRAL BATTERY MONITORING SYSTEM 1
B1
BATTERY 1
BM2
CENTRAL BATTERY MONITORING SYSTEM 2
B2
BATTERY 2
BMn
CENTRAL BATTERY MONITORING SYSTEM n
Bn
BATTERY n
151
REMOTE OPERATOR'S TERMINAL